Multi-Link Iridium Satellite Data Communication System

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M.S. Thesis Defense

January 28, 2004

Committee

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Presentation Outline

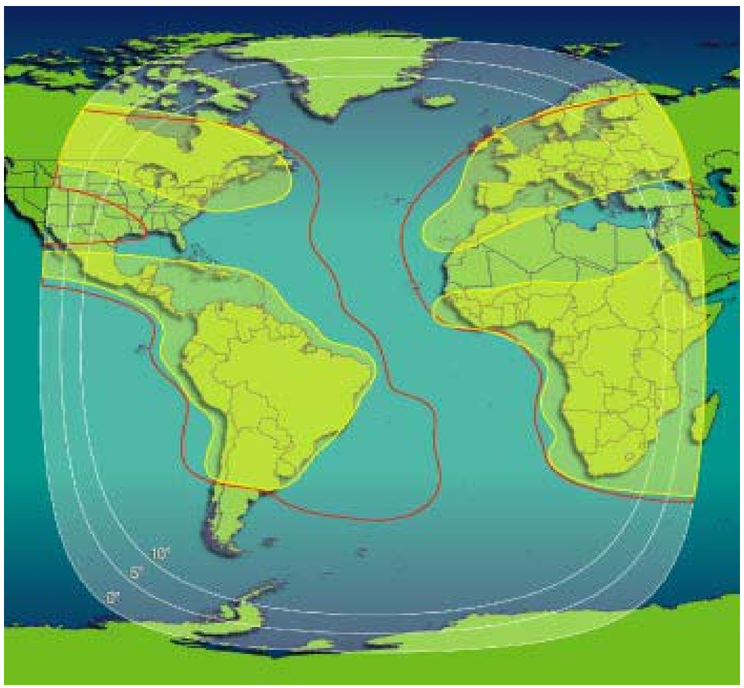
- Motivation and Introduction
- Background
- Multi-channel Iridium System Design
- 4-Channel System Implementation
- Field Tests and Results
- Conclusions and Future Work

Motivation

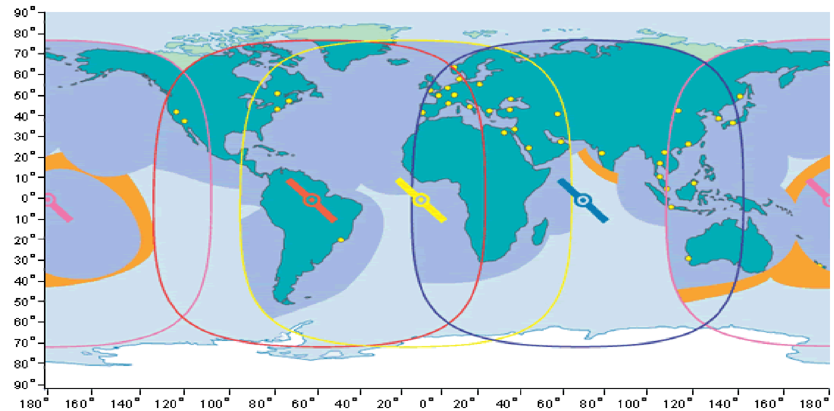
- **Polar Radar for Ice Sheet Measurements (PRISM)**
  - The communication requirements of PRISM field experiments in Greenland and Antarctica include
    - Data telemetry from the field to the University
    - Access to University and web resources from field
    - Public outreach to increase the interest of student community (K-12) in scientific research and enable the science community to virtually participate in polar expeditions
- **Generic data communication for Remote field research**
  - Mainstream communication system for polar science expeditions, field camps in Arctic/Antarctic and other research purposes
  - Government and security use

Introduction – Commercial Satellite Systems

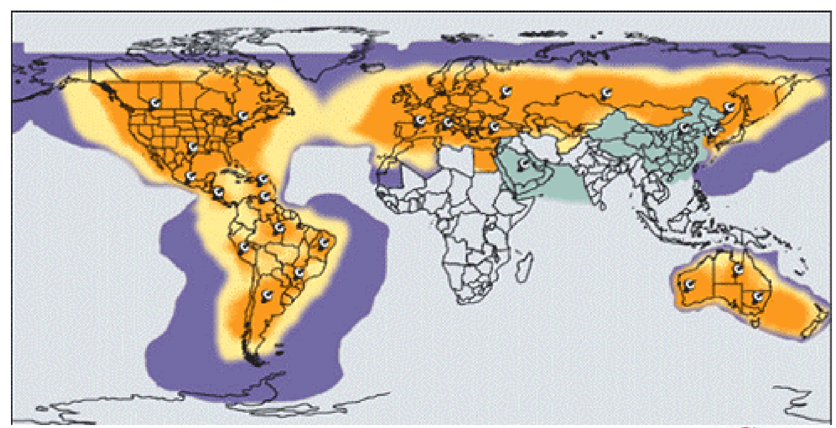
- Polar regions do not have conventional communication facilities (dial-up, DSL, Cable Modem, etc) and are not serviced by most of the major broadband satellite systems.



Intelsat



Inmarsat



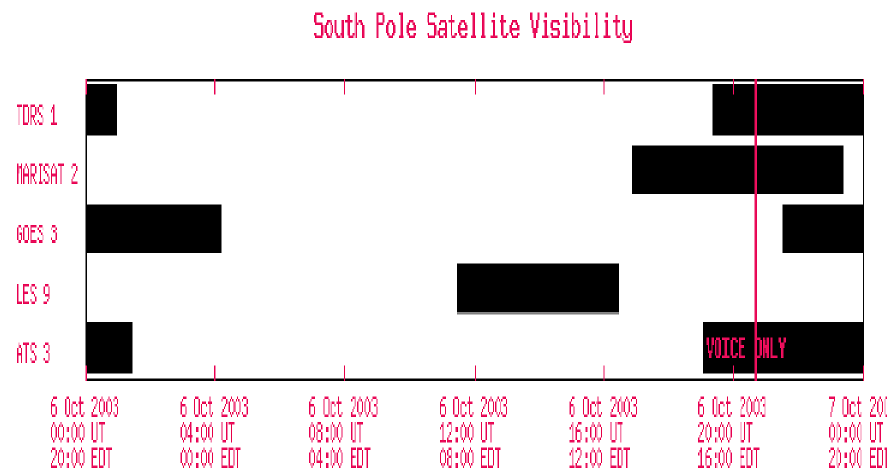
Globalstar

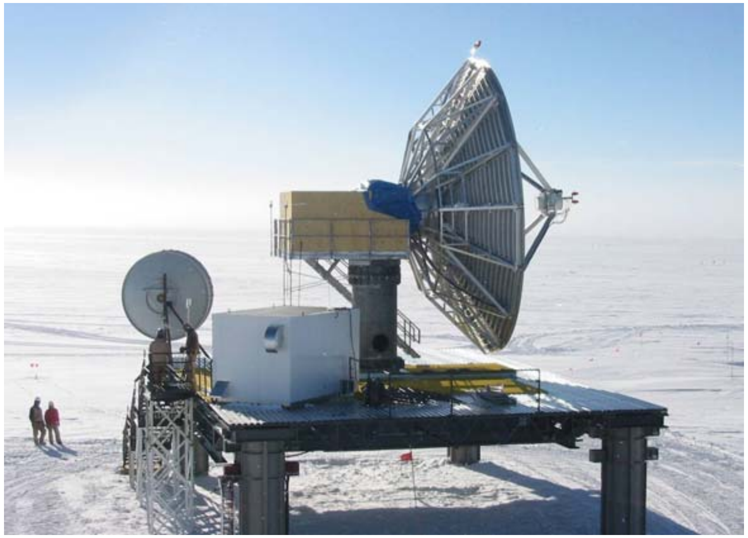
Introduction - Iridium Satellite System

- The only satellite system with true pole-to-pole coverage
- 66 low earth orbiting (LEO) satellites with 14 spares
- It has onboard satellite switching technology which allows it to service large areas with fewer gateways
- Since it was originally designed as a voice only system, it provides a low data rate of 2.4Kbps
- Not practical to be used as a main stream/ life-line communication system

Introduction – Special Purpose Satellite Systems

- NASA satellites like ATS3, LES9, GOES, TDRS 1,and MARISAT2 provide broadband access to Polar Regions
- Geo-synchronous, they have a limited visibility window at Poles – typically 10-13 hrs/day.
- High satellite altitude and low elevation angles (1-2^{0}) result in extremely large field equipment.
- May not be readily available





20 m diameter Marisat and GOES antenna at South Pole

Introduction – Problem Statement

- **Problem Statement**

  A reliable, lightweight, portable and easily scalable data/Internet access system providing true Polar coverage.

- **Solution**

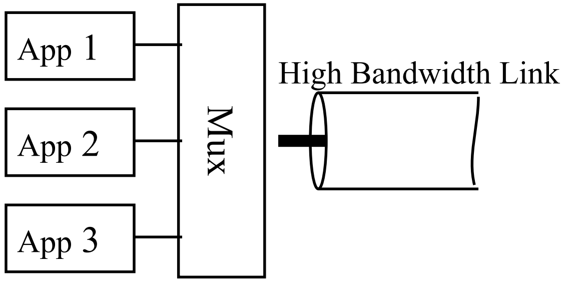
  Implement a multi-link point-to-point Iridium communication system to combine multiple satellite links to obtain a single logical channel of aggregate bandwidth.

Background - Iridium

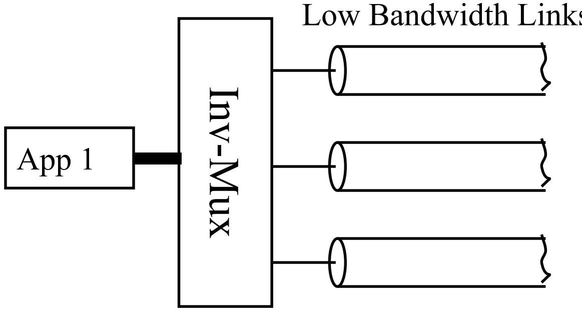
Satellite Type	LEO
Satellite altitude	780 km
Minimum elevation angle	8.2^0
Average satellite view time	9-10 minutes
Access scheme	FDMA and TDMA
Maximum number of located users	80 users in a radius of 318 km
Theoretical throughput	2.4 – 3.45 Kbps
Type of data services	Iridium-to-Iridium, Iridium-to-PSTN

Background - Inverse Multiplexing

- **Traditional Multiplexing** - Data from a multiple applications/users sent over a single high bandwidth link.
- **Inverse Multiplexing** - Data from a single application is fragmented and or distributed over multiple low bandwidth links.
- Increases the available bandwidth per application significantly
- Multi-link point-to-point protocol (MLPPP), an extension to the PPP is a packet based inverse multiplexing solution
- Overhead of 12 bytes
- Fragmentation of network layer protocol data units (PDU's) into smaller segments depending upon the PDU size, link MTUs and the number of available links.



Multiplexing

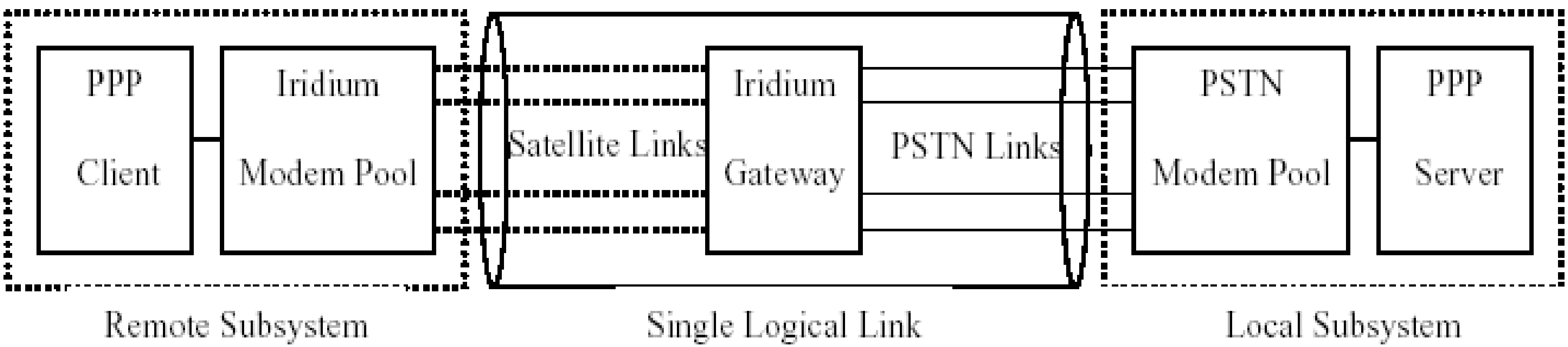


Inverse multiplexing

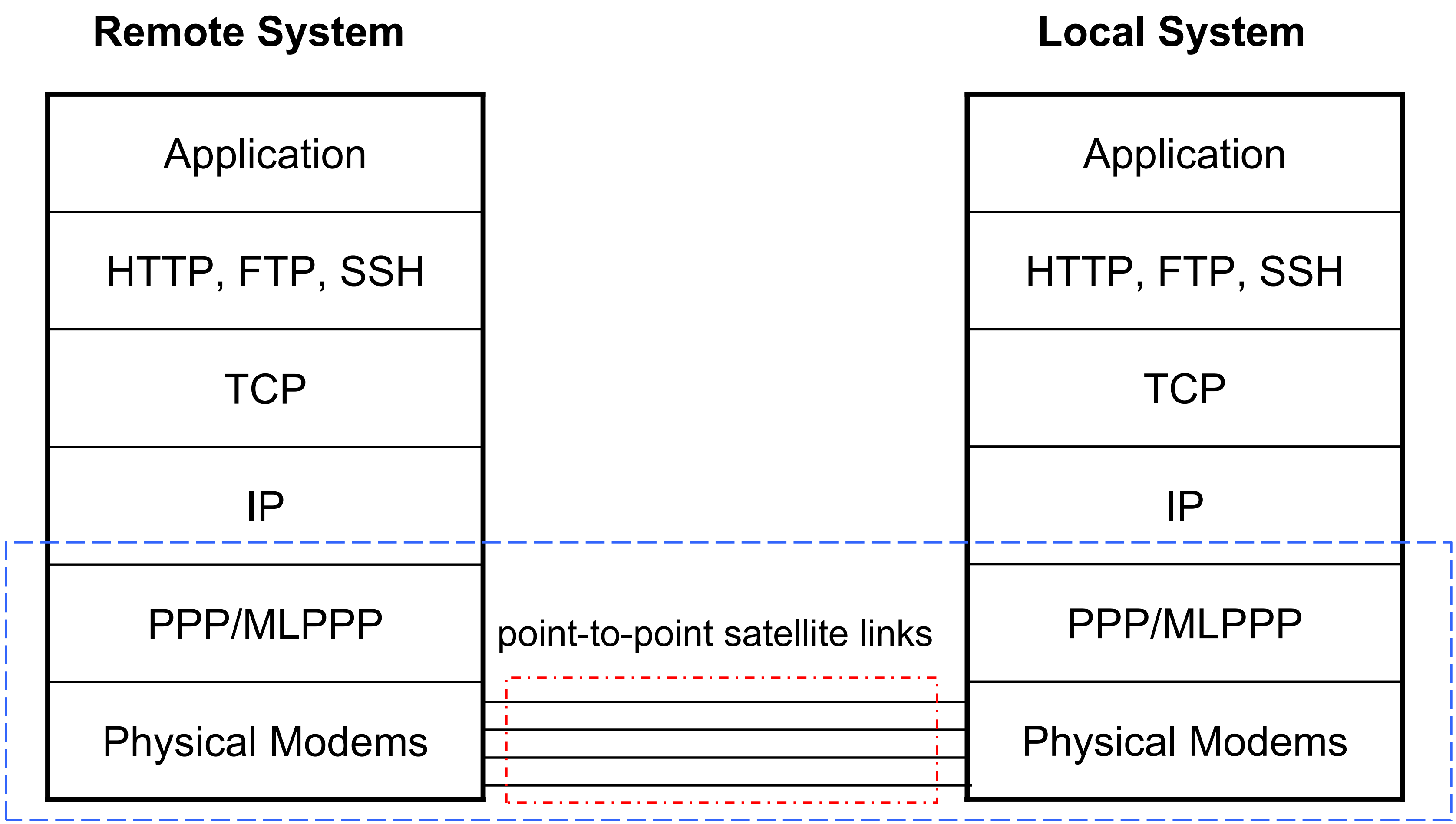
Multi-channel Iridium System – Design

The design requirements of the system are as follows.

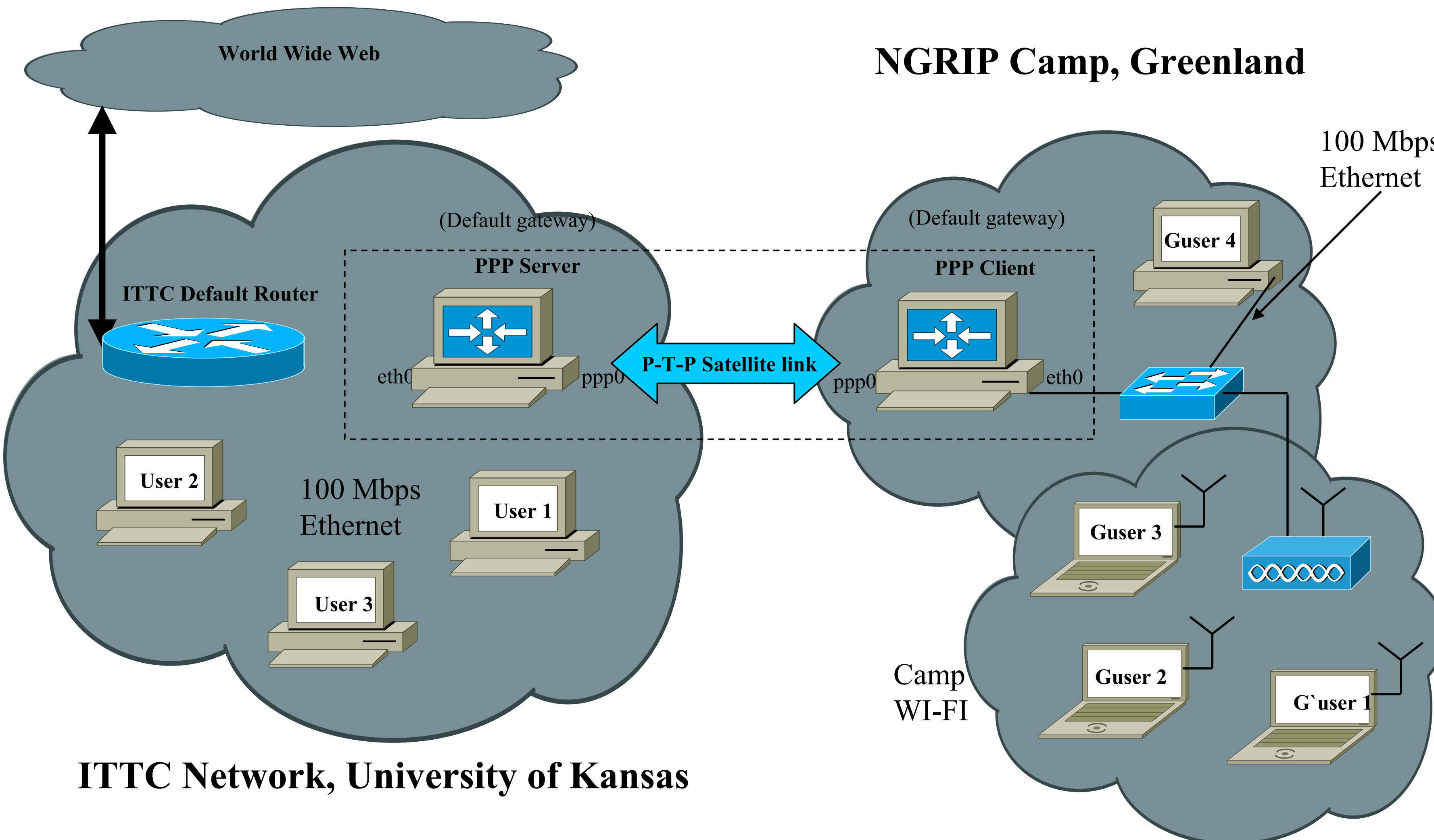
- The multi-channel implementation should maximize the throughput.
- To support real-time interactions, the system should minimize the end-to-end delay.
- The overall system should be reliable and have autonomous operation so as to handle call drops and system/power failures in remote field deployment.



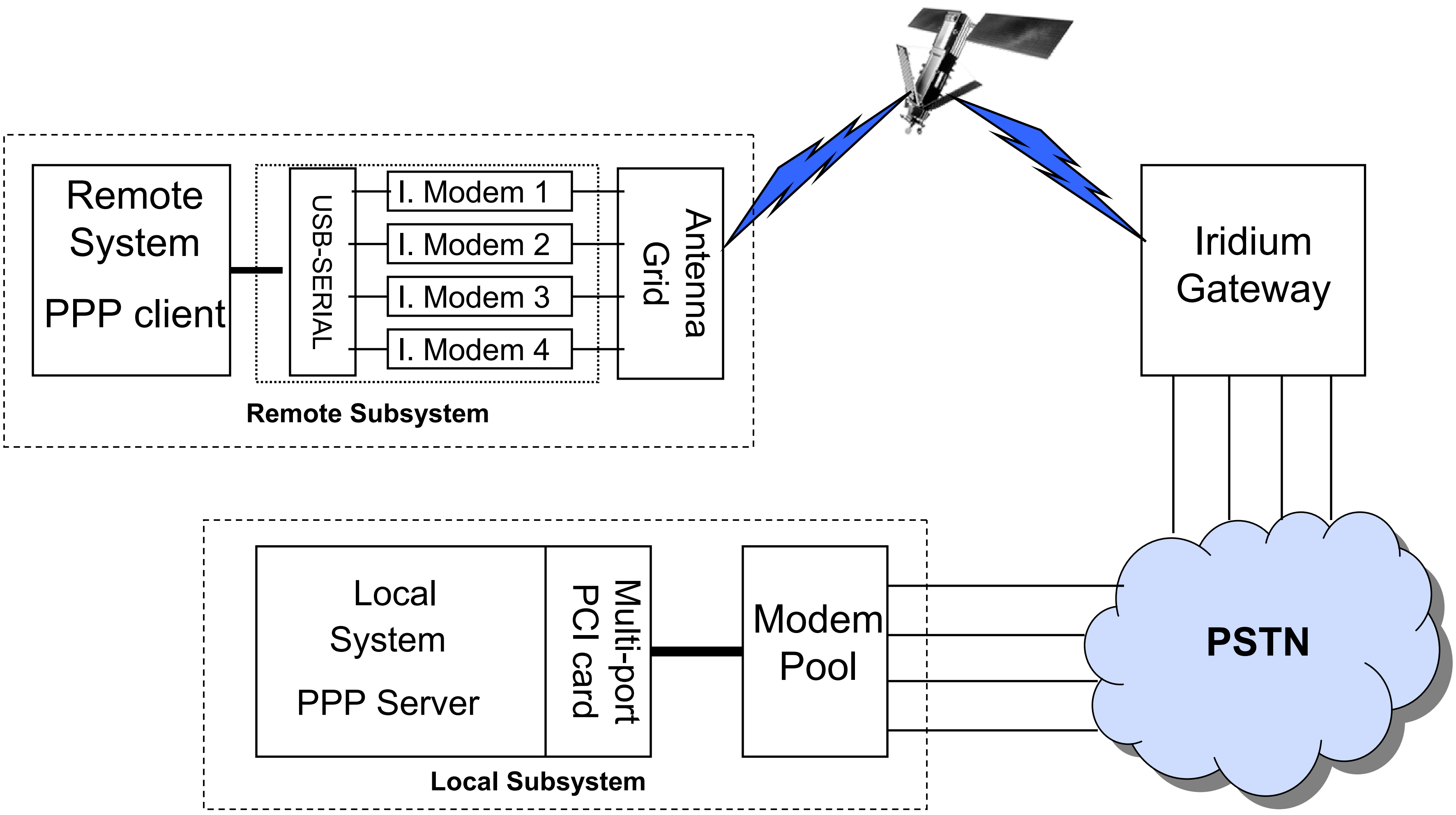
Multi-channel Iridium System – Protocol Stack



Multi-channel Iridium System – Network Architecture



4-Channel Iridium System Implementation



4-Channel System – Implemented at KU

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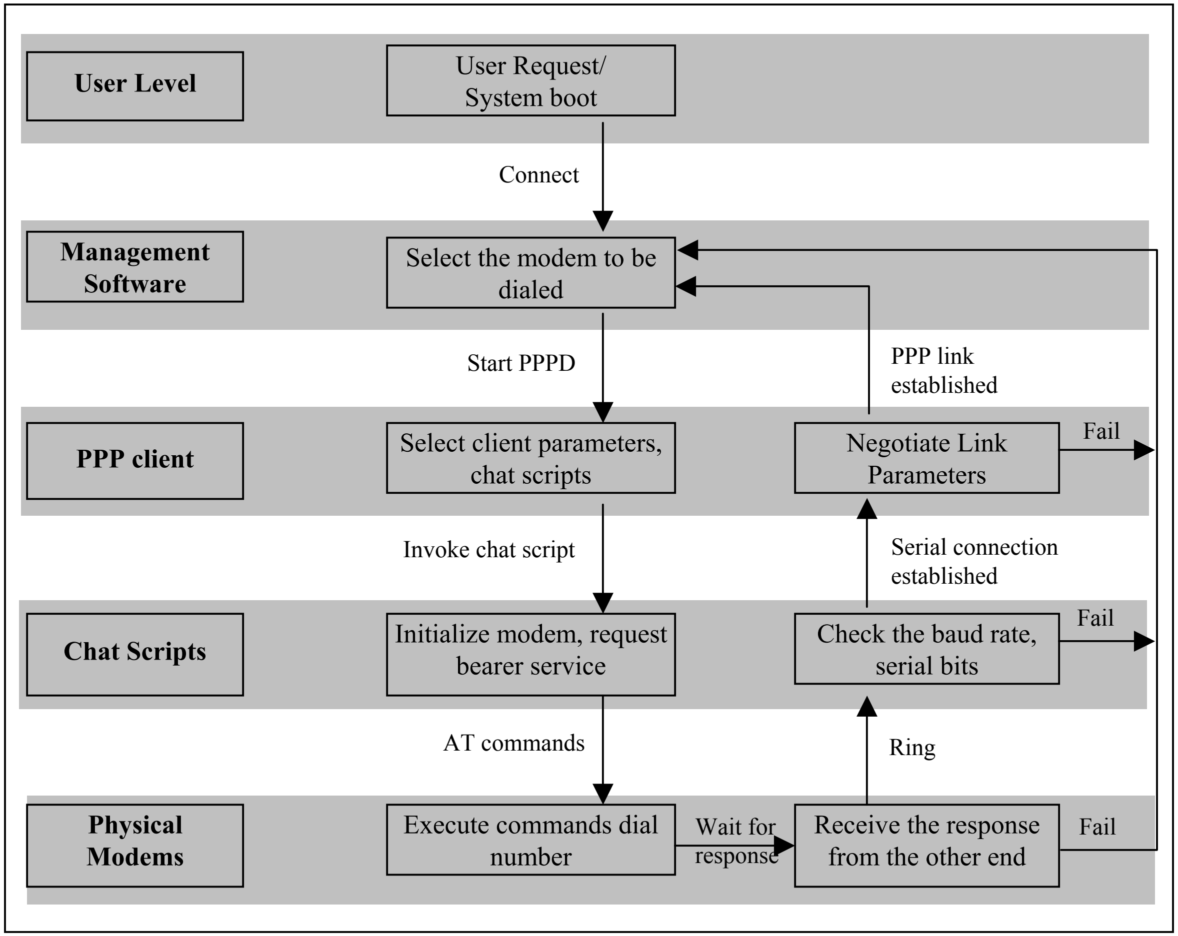
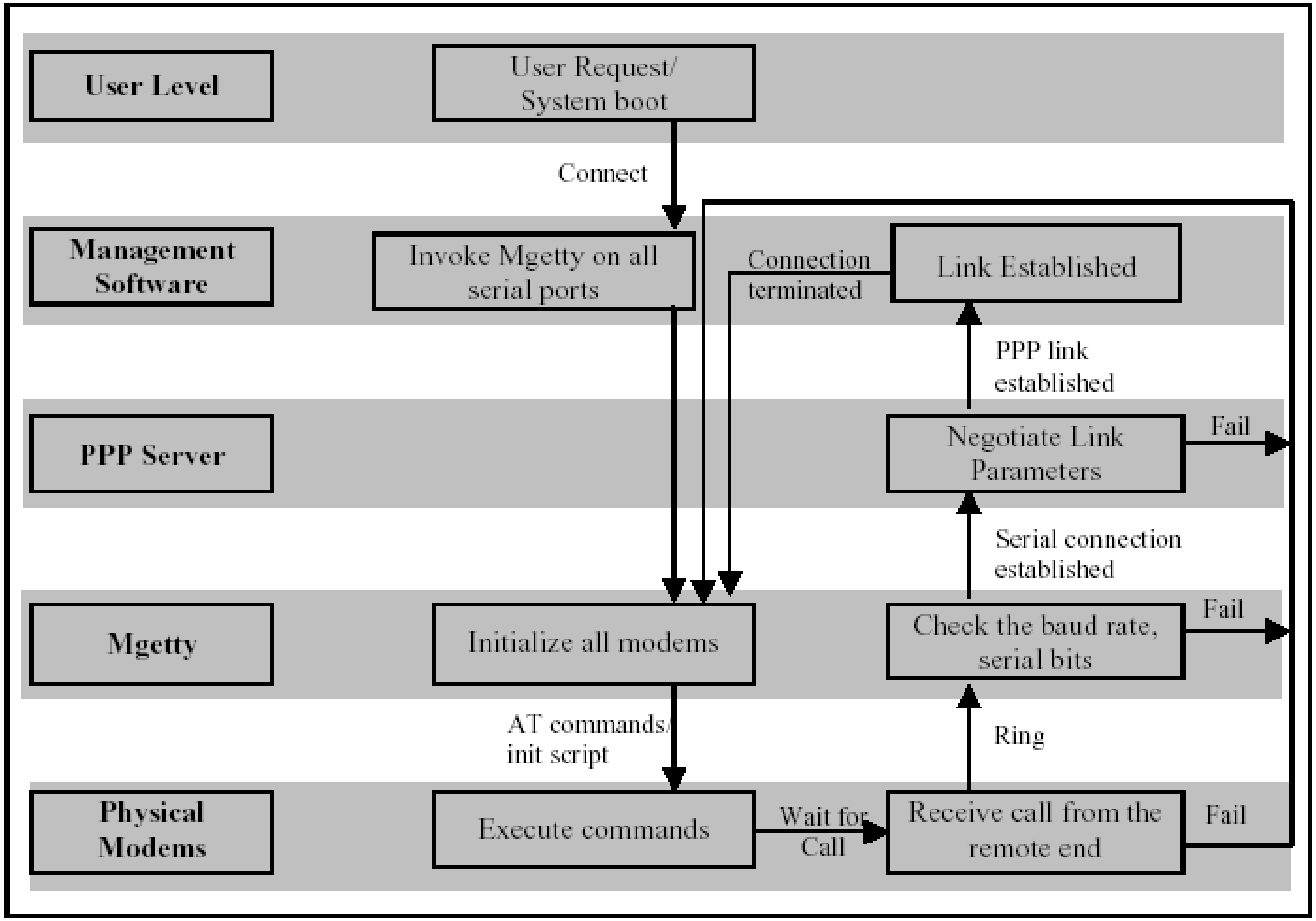
4-Channel System – Software Overview



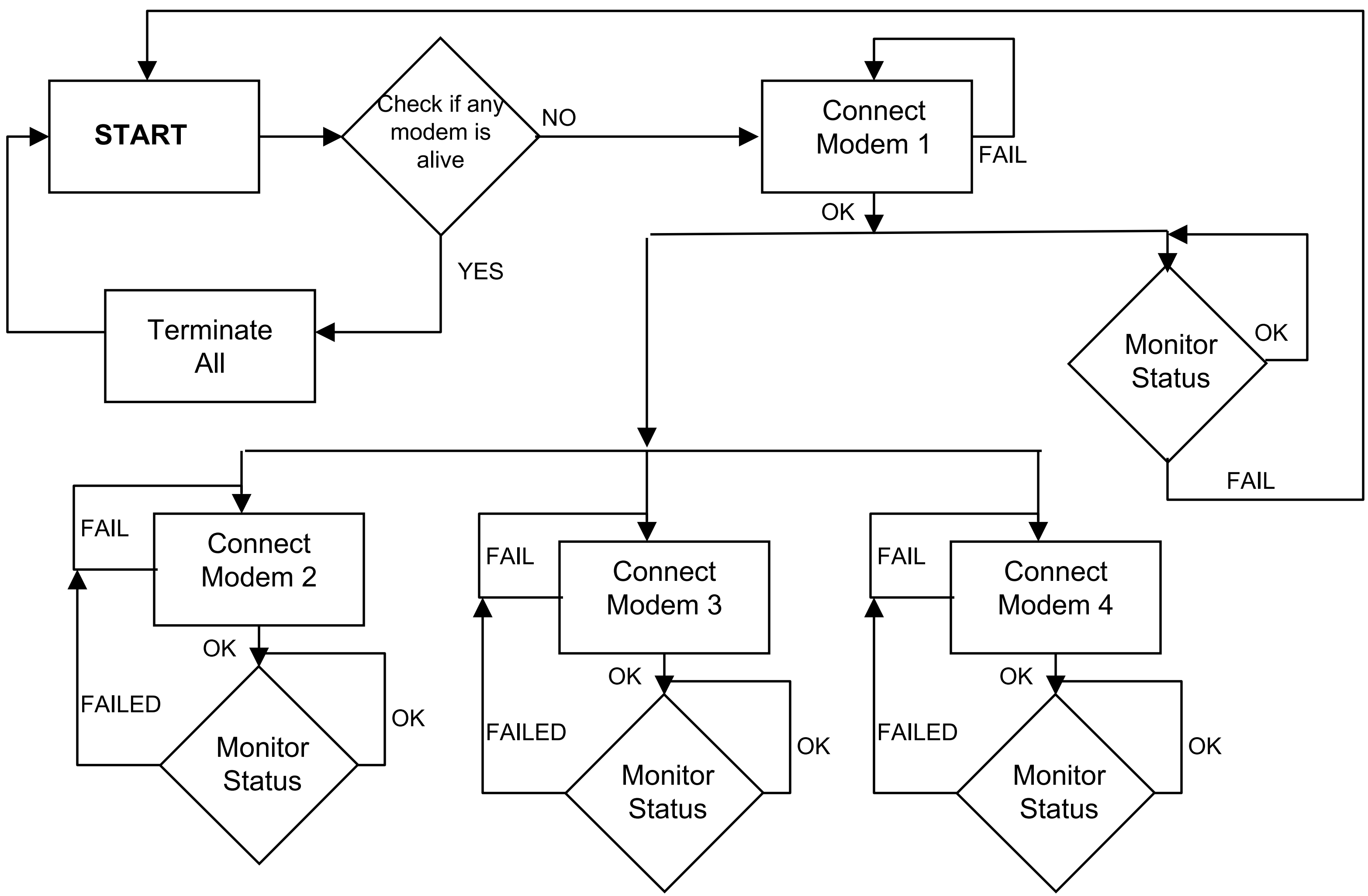
Software flow control at the PPP client

4-Channel System – Software Overview

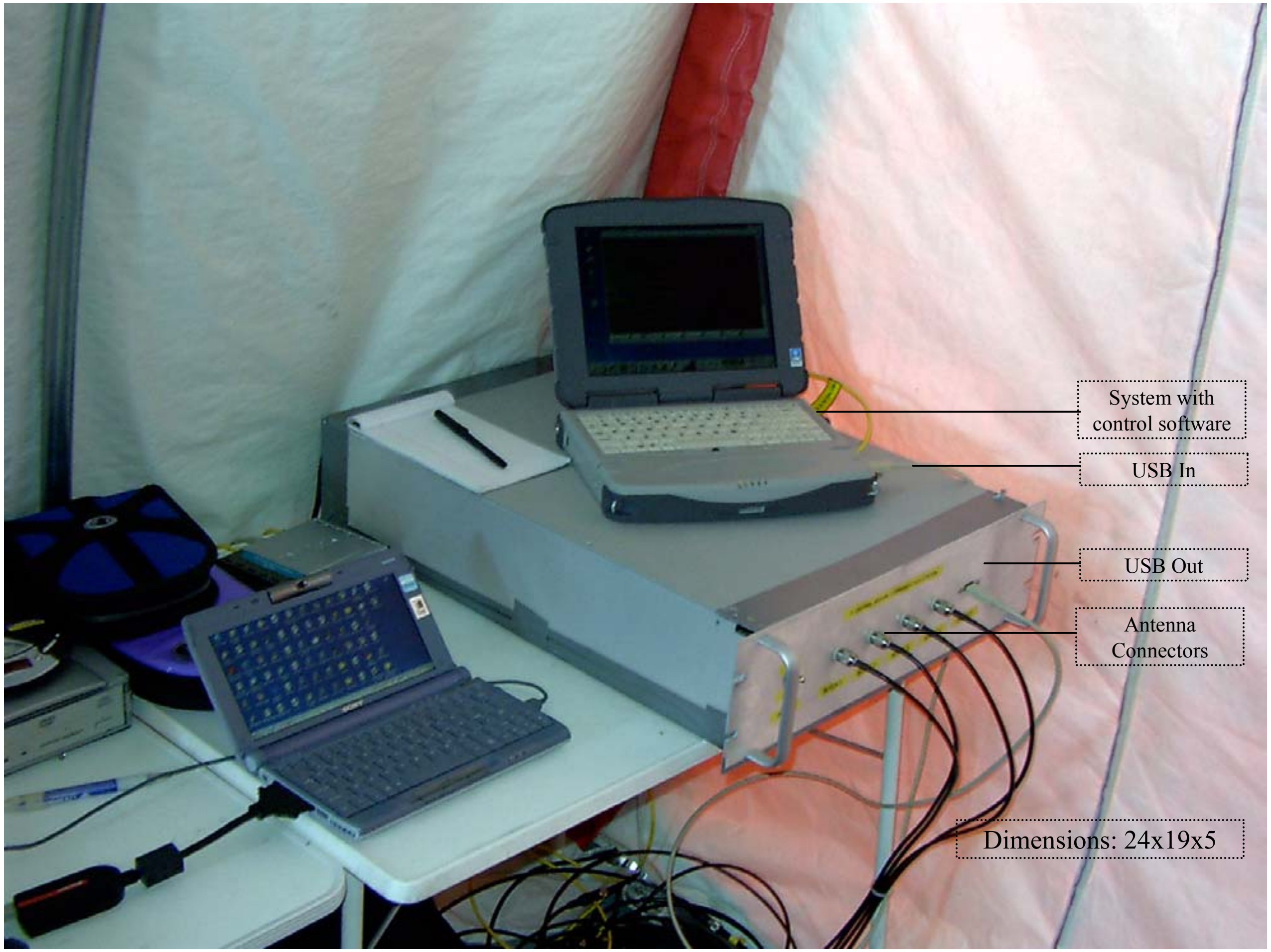


Software flow control at the PPP Server

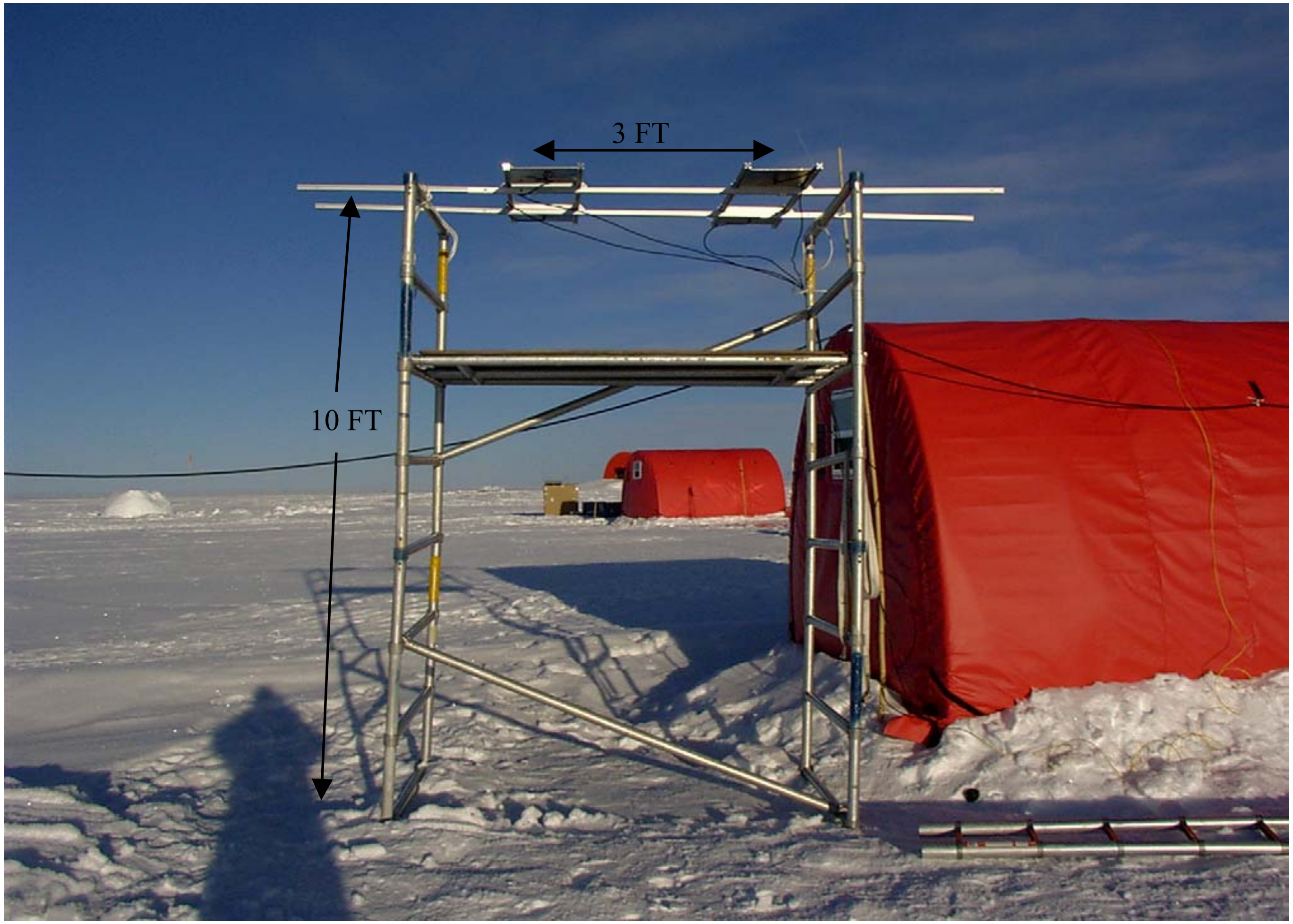
4-Channel System – Modem Flow Control



Field Tests and Results – Field implementation



Field Tests and Results – Antenna Setup



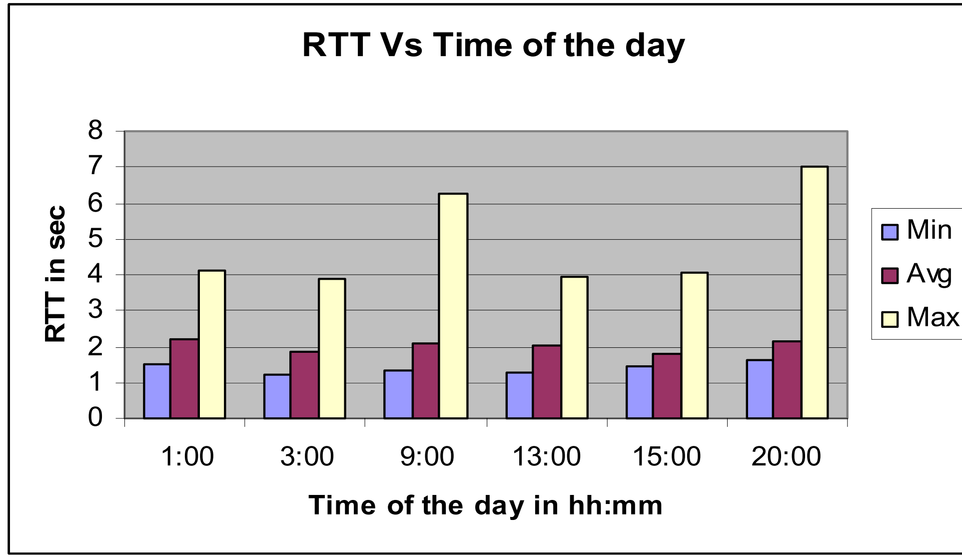
Results – Delay and Loss Measurement

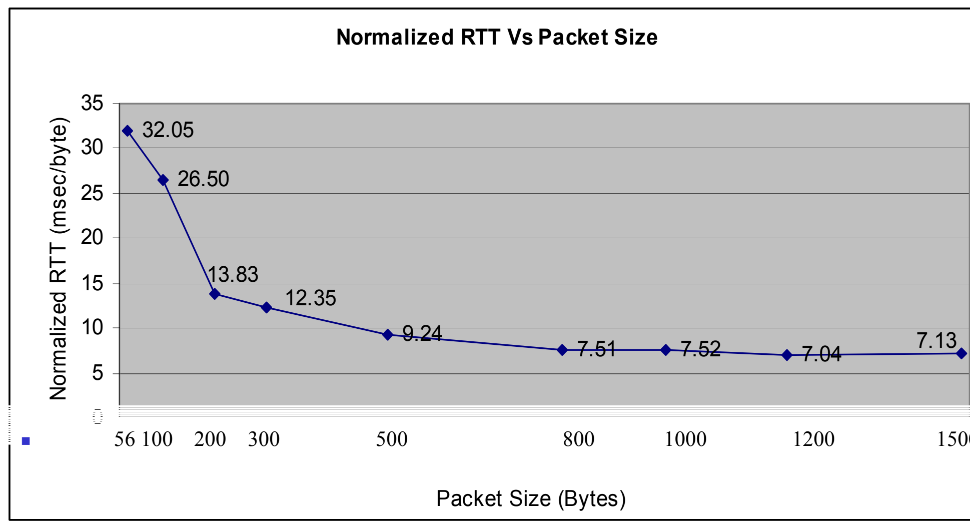
- Ping tests between the two machines at the end of the of satellite link
- One way propagation delay = (800+8000+6000)Km / (3e6)Km/sec= 49msec
- Transmission time for 64 bytes@2.4Kbps = 64*8/2400=213msec
- Theoretically, the RTT delay =2*(49+213)= 524msec+delay at the gateway
- Test results show an average RTT delay of 1.8 sec, which may be attributed to the inter-satellite switching and delay at the gateway

Packets sent	Packets received	% Loss	RTT (sec)			
			Avg	Min	Max	mdev
50	50	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

Results – Delay Measurement

- Random variation of delay
- High mean deviation
- Delay increases linearly with packet size
- Normalized delay is almost constant for MTU sizes > 800 bytes
- Changing distance between the user and satellite as well as between satellites themselves (ISLs)
- Non-uniform traffic distribution, varying delays on different routes





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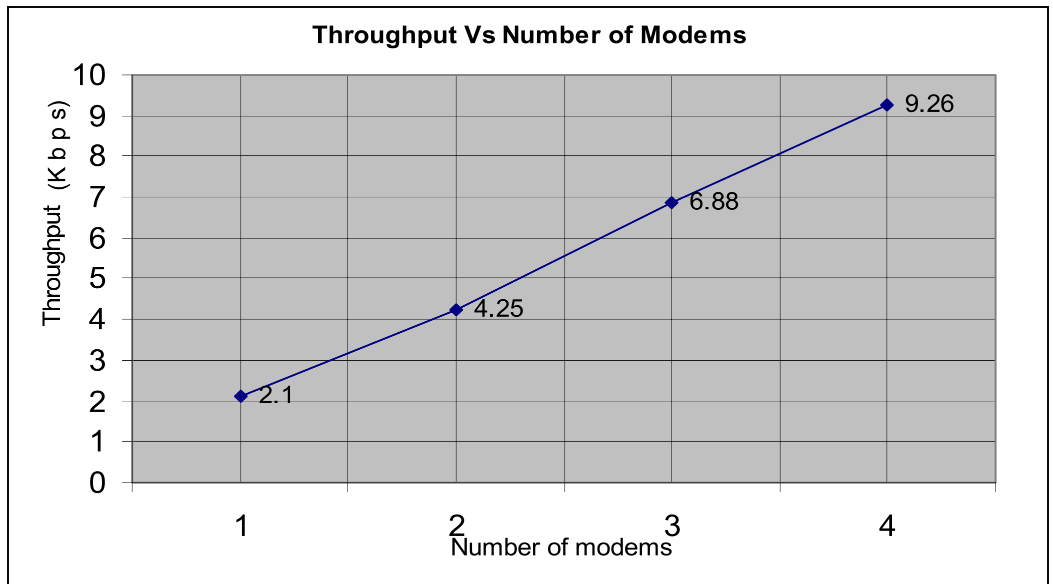
Results – Throughput

- Tools used – TTCP, IPERF
- Throughput varies to some extend due to RTT variation
- Efficiency > 90%

Method	1 Modem	2 Modems	3 Modems	4 Modems
Iperf	2.1	4.0	7.0	9.6
Iperf	1.9	3.9	7.0	9.3
Iperf	1.7	4.5	6.8	9.7
Ttcp	2.29	4.43	6.6	8.9
Ttcp	2.48	4.40	7.0	8.78
Average	2.1	4.25	6.88	9.26

Effective throughputs during large file transfers

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



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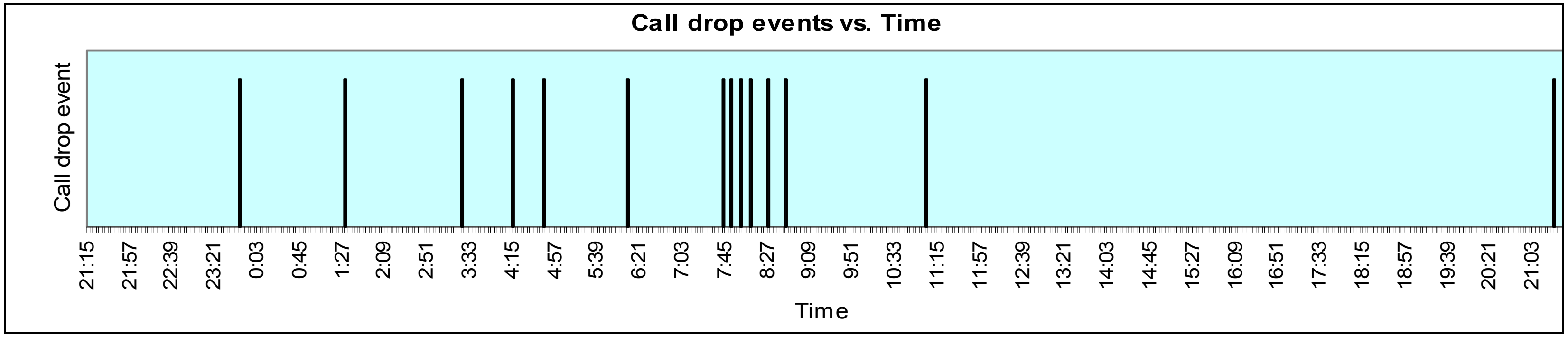
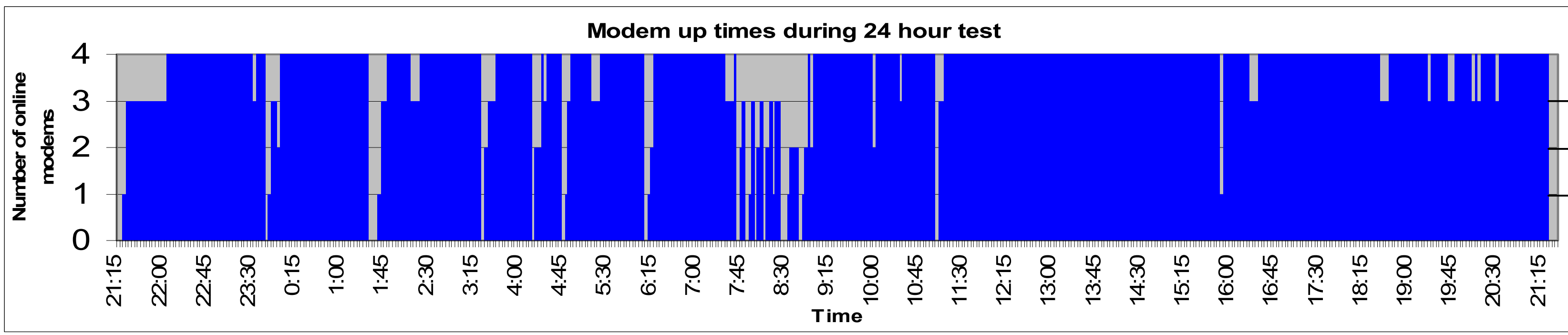
Results – Reliability: 10th July 24 hr test



Total :

13 Call drops



Uptime %

80.6

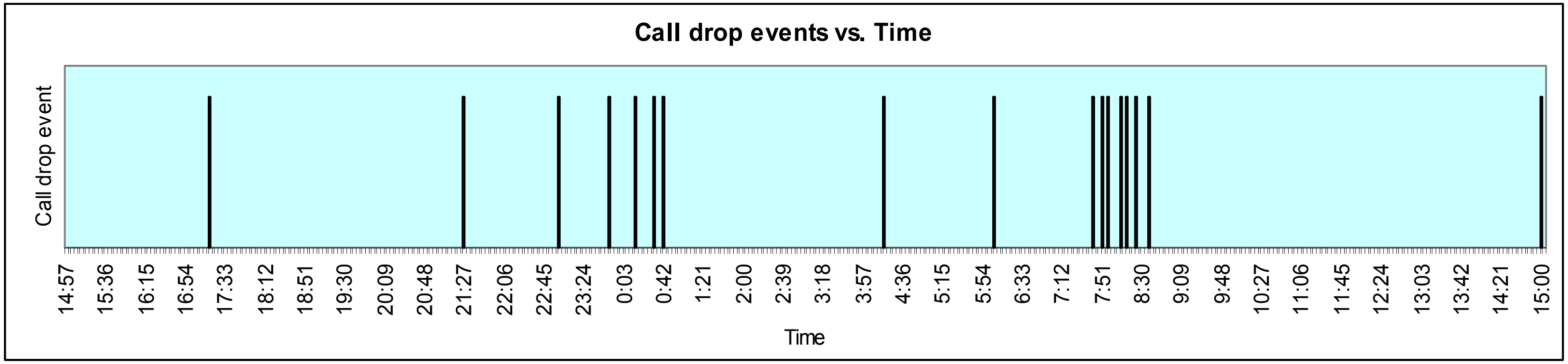
91.8

94.7

96.8

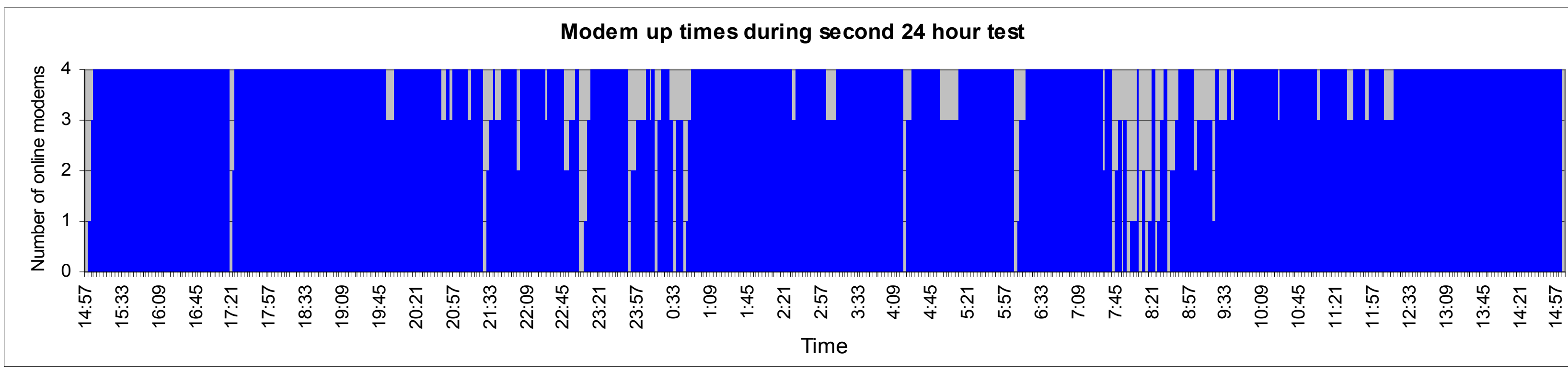
Time interval between call drops (minutes)	146	106	114	50	25	84	89	8	7	7	17	11	137	618

Results – Reliability: 12th July 24 hr test



Total :

16 Call drops



Uptime %

80

92

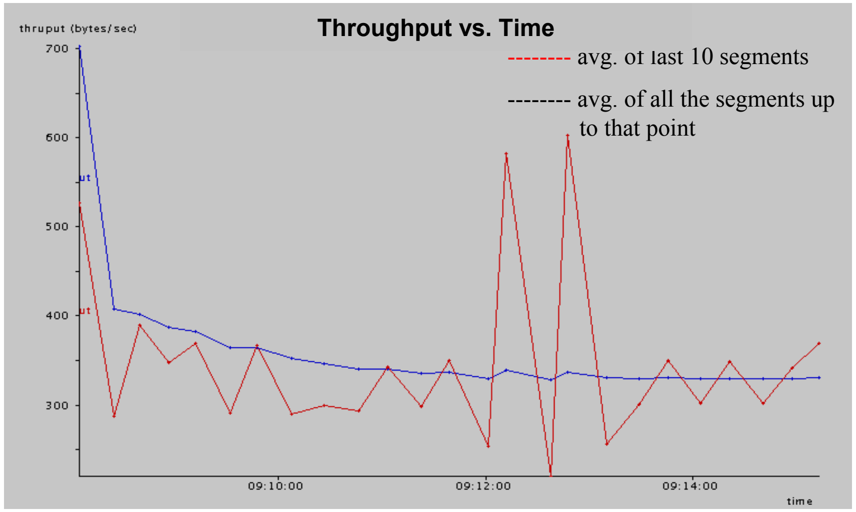
95

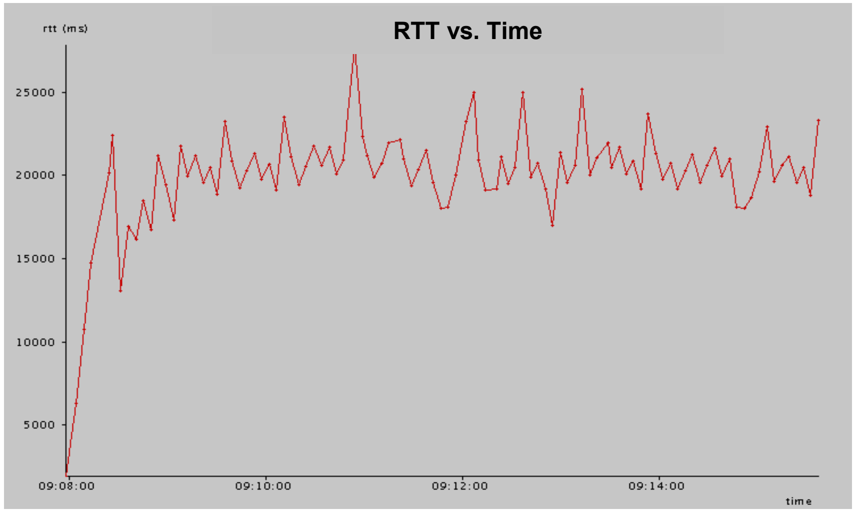
96

Time interval between call drops (minutes)	135	248	93	40	26	16	8	211	108	91	8	5	6	5	8	7	386

Results – TCP performance of a single link

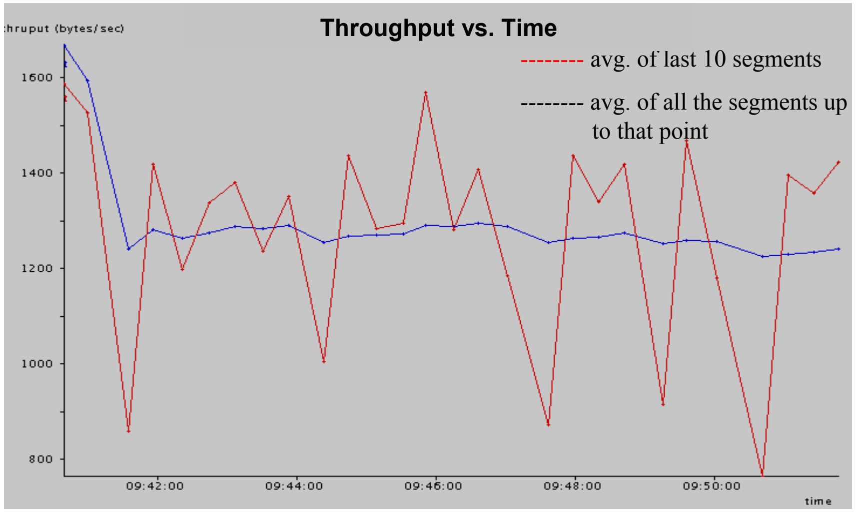
- TCP Version – TCP SACK
- Throughput of a segment is defined as the size of the segment seen divided by the time since the last segment was seen (in this direction).
- RTT is defined as the time difference between the instance a TCP segment is transmitted (by the TCP layer) and the instance an acknowledgement of that segment is received.
- The average throughput of the connection is 2.45Kbps.
- The average RTT was found to be 20 seconds
- Bandwidth Delay Product (BDP) = 2400*20/8 = 6000 bytes = 4 segments.
- Due to low throughput, the BDP is small.

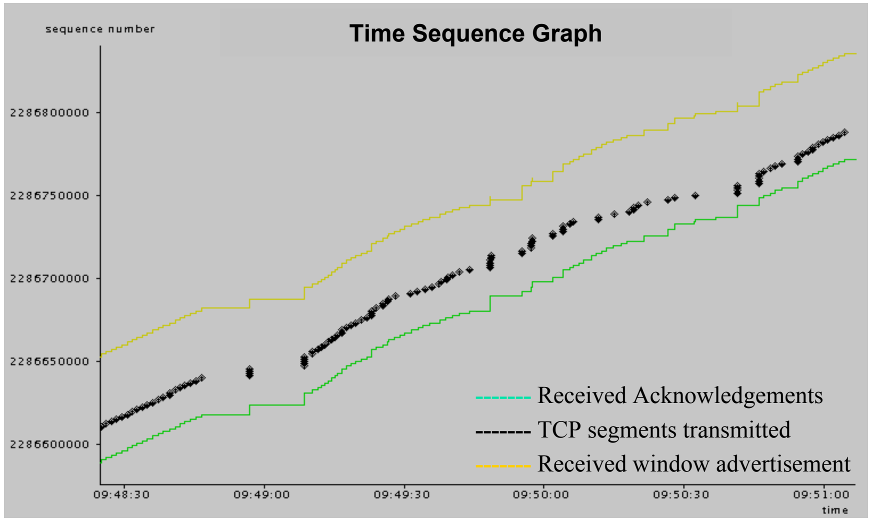


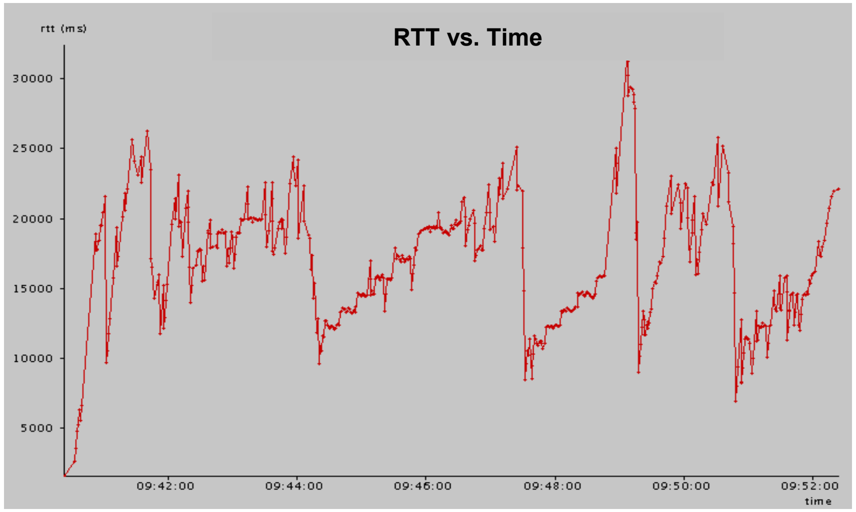


Results – TCP performance of a 4-channel system

- The average throughput obtained - 9.4 Kbps
- The average RTT observed - 16.6 seconds
- Factors affecting throughput and RTT
  - TCP Slow start
  - MLPPP fragmentation
  - Random delay variation
  - TCP cumulative acknowledgments

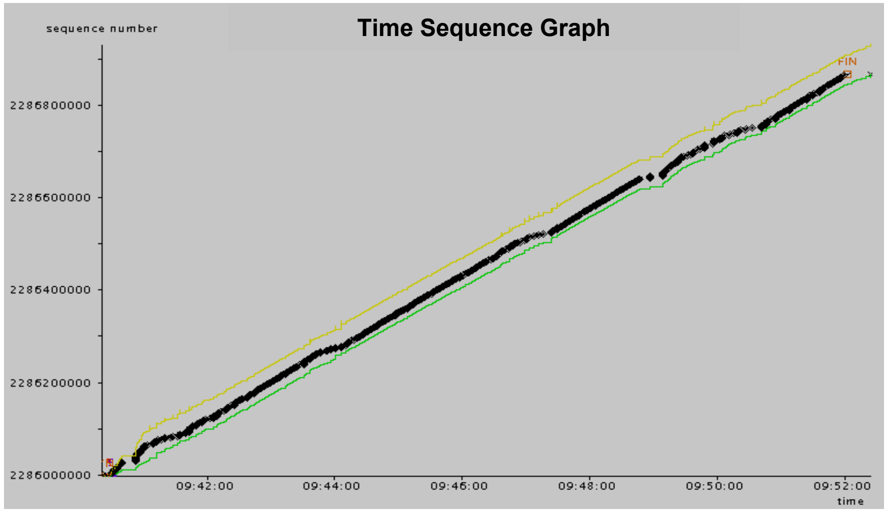


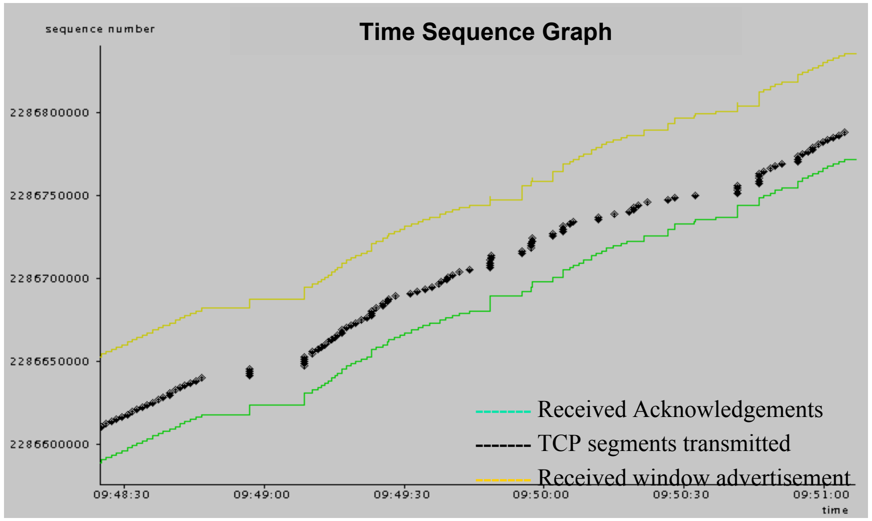


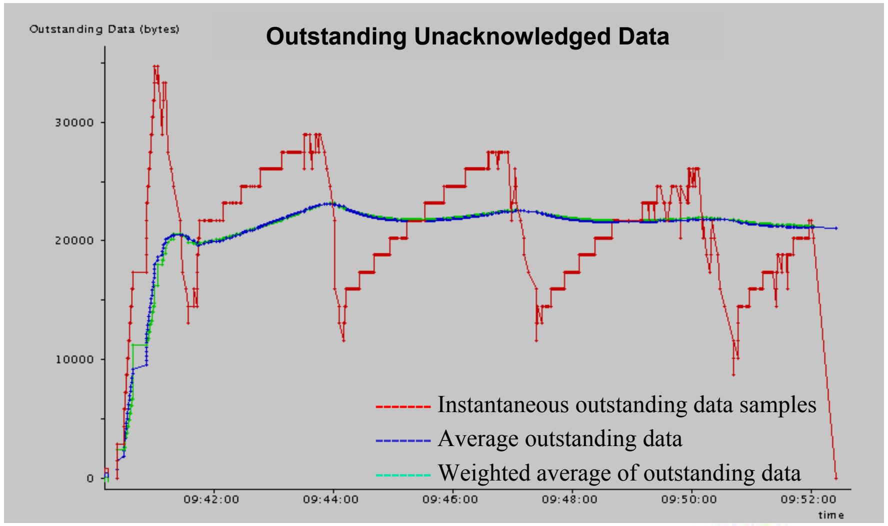


Results – TCP performance of a 4-channel system

- Outstanding Unacknowledged data and Congestion window

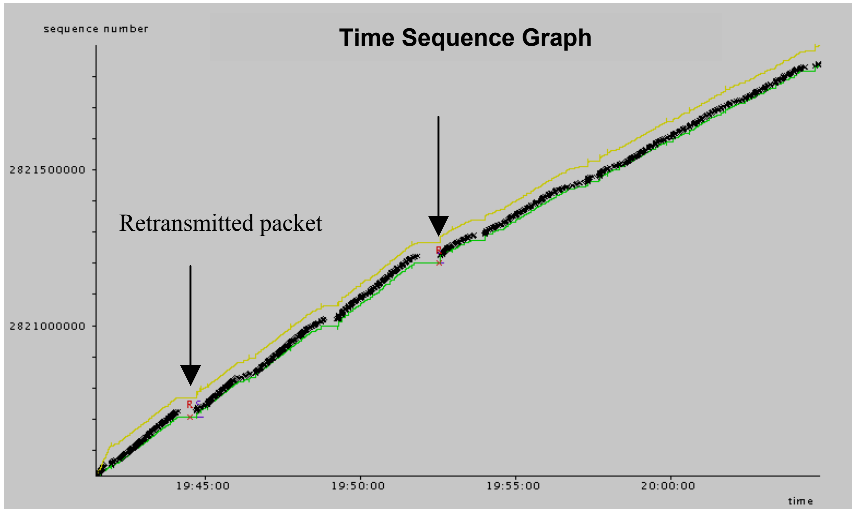


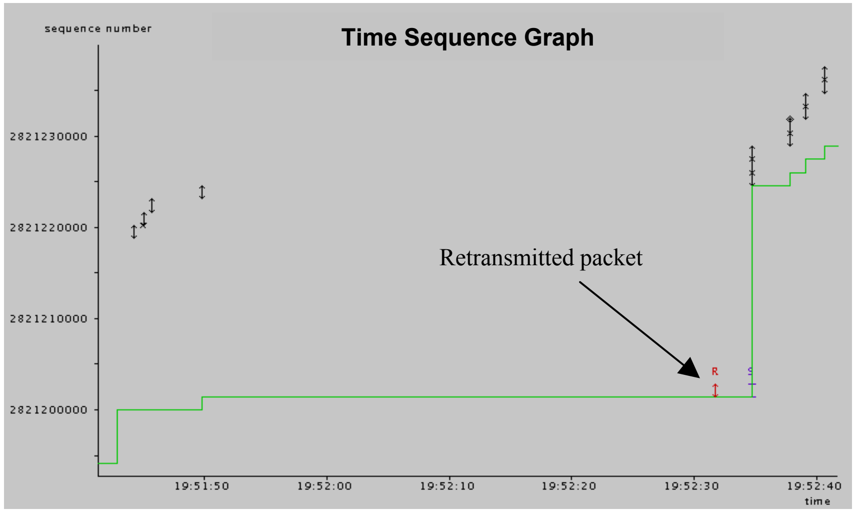




Results – TCP performance degradation due to packet loss

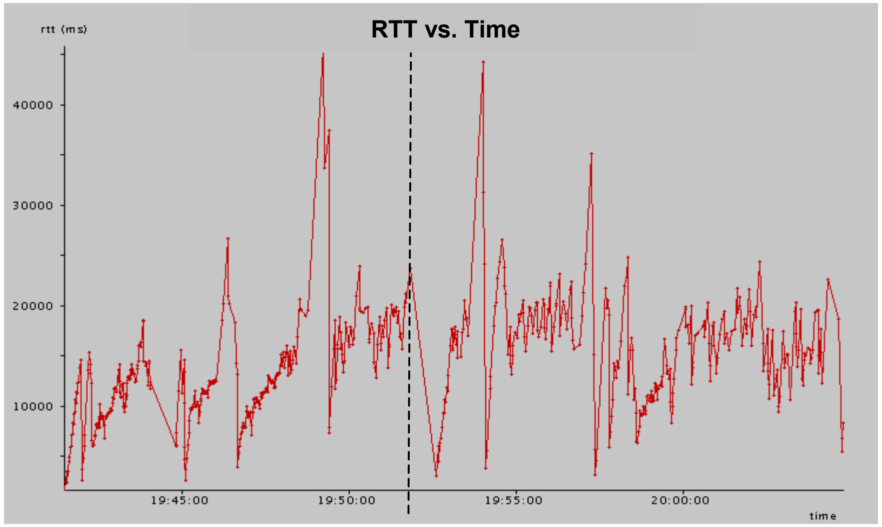
- Low packet loss, long time experiments needed to determine the performance degradation
- Two packet losses were observed in the FTP video upload resulting in packet retransmissions
- Packet losses usually occur during call hand-offs
- Retransmission time outs (RTO) is very large due to high RTT and high mean deviation

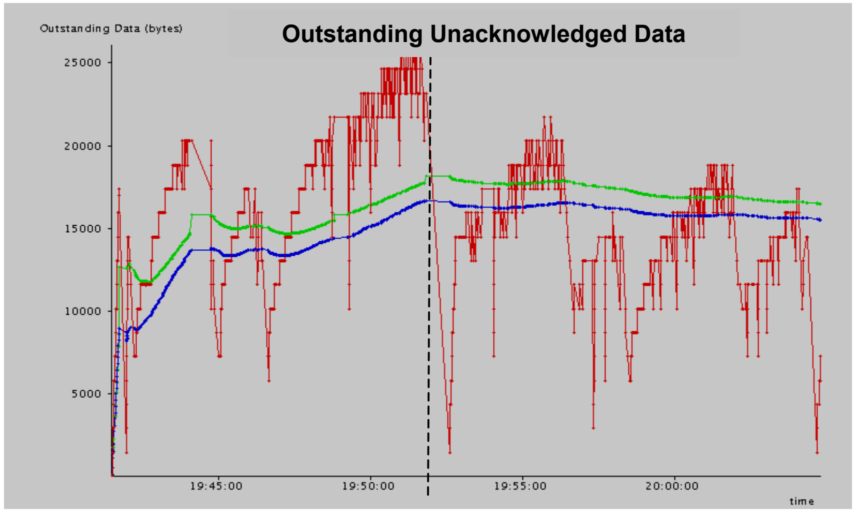


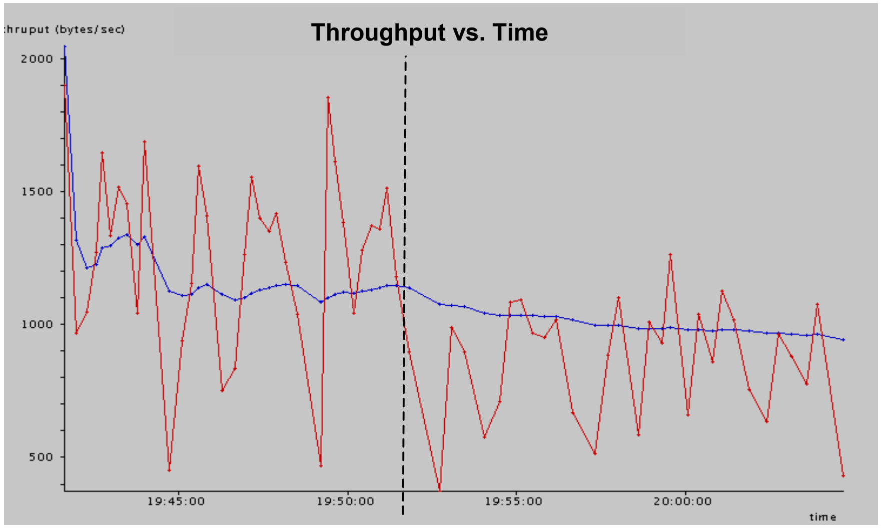


Results – TCP performance degradation due to packet loss

- Effect on the TCP performance due to packet loss
- Decrease in the throughput following the packet loss
- RTT peaks around the packet loss
- The average throughput of the connection is observed to be 7.44 Kbps.

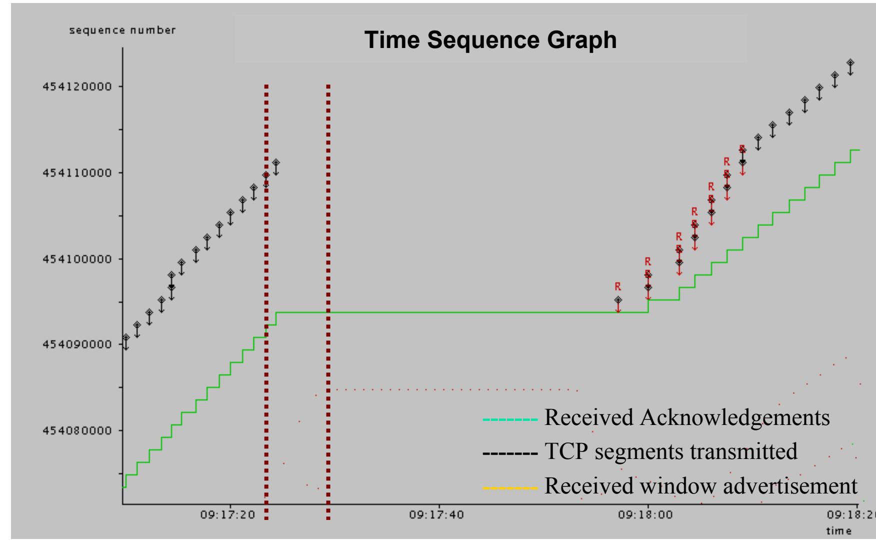


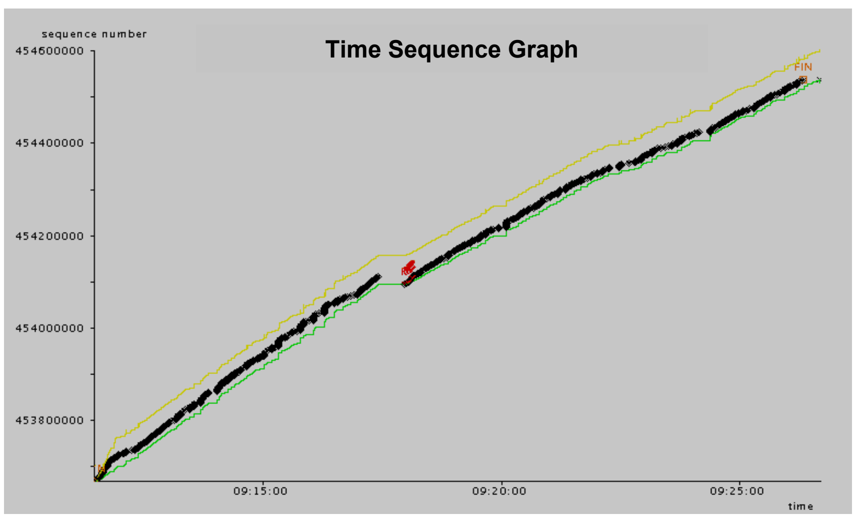


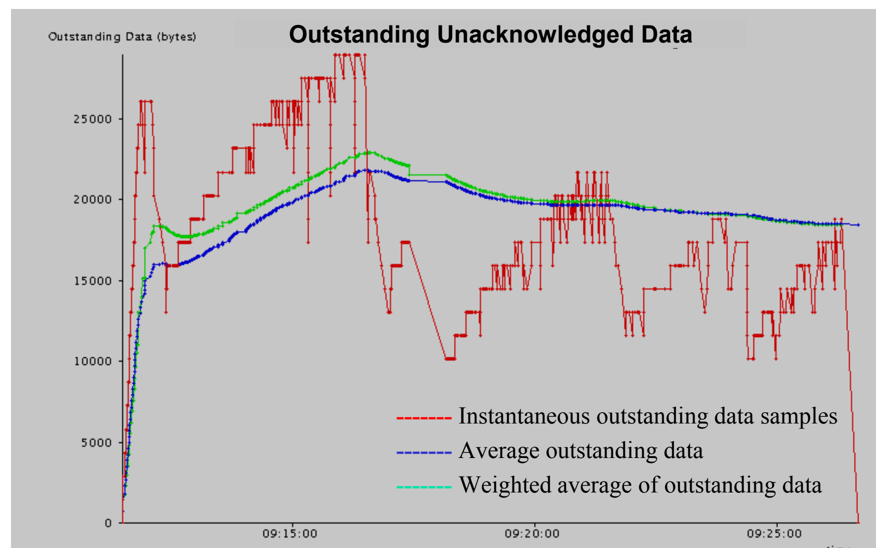


Results – TCP performance degradation due to call drop

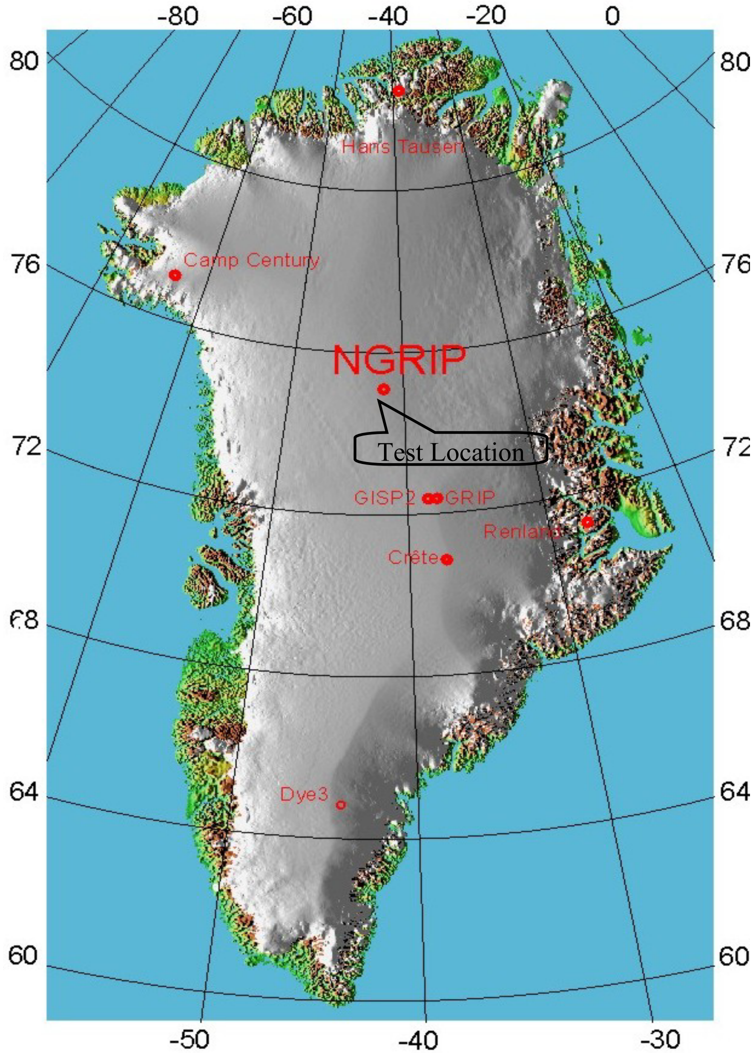
- Packet loss due to a call drop on one links of the multilink bundle
- A finite amount of time for the data link layer realize the link has failed
- Large RTO timer
- The entire window of packets (12 in this case) and acknowledgements that are in flight on that particular link are dropped.
- Throughput of the connection – 7.6 Kbps.







Results – Mobile tests



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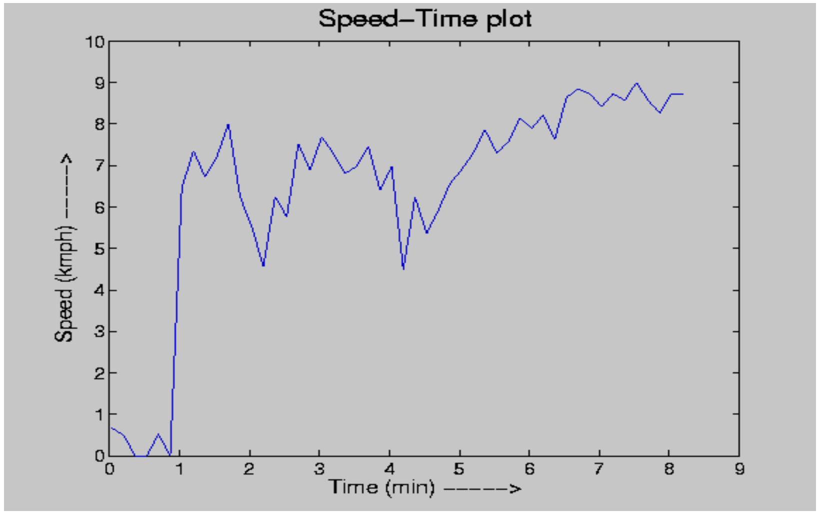
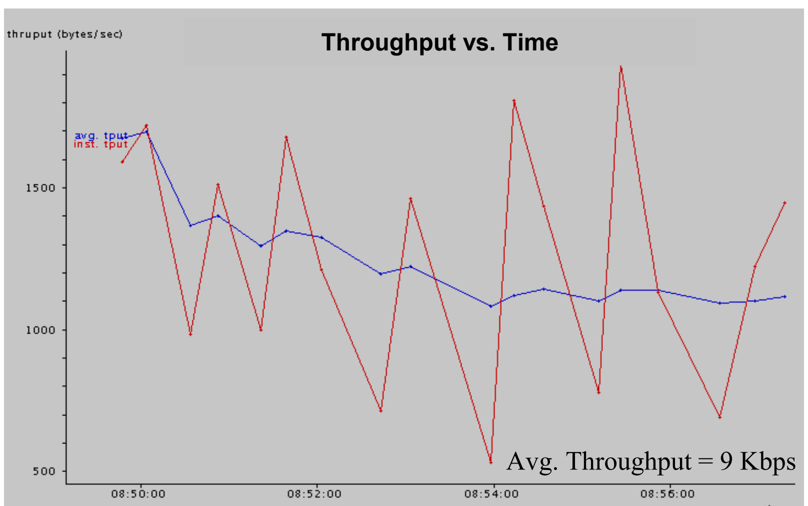
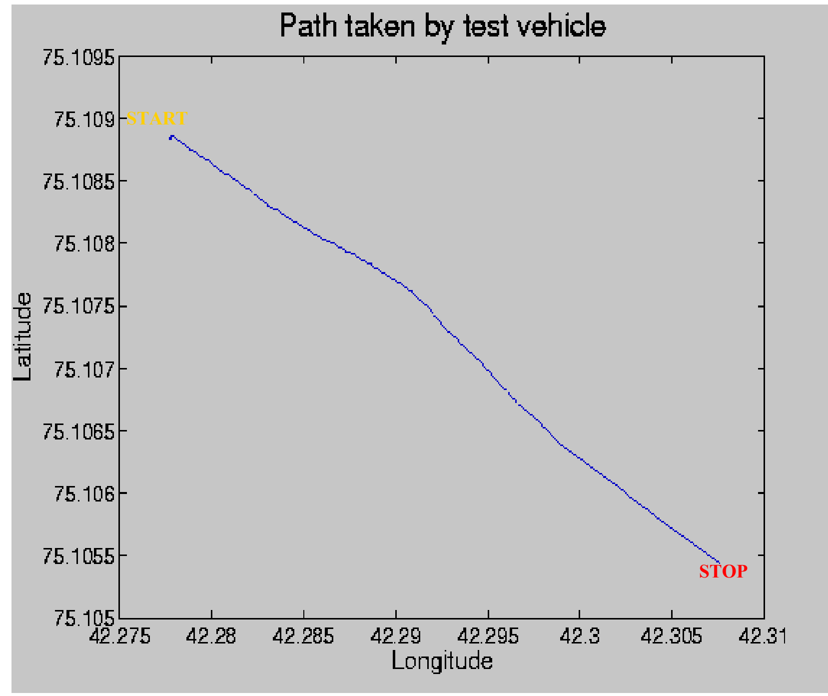
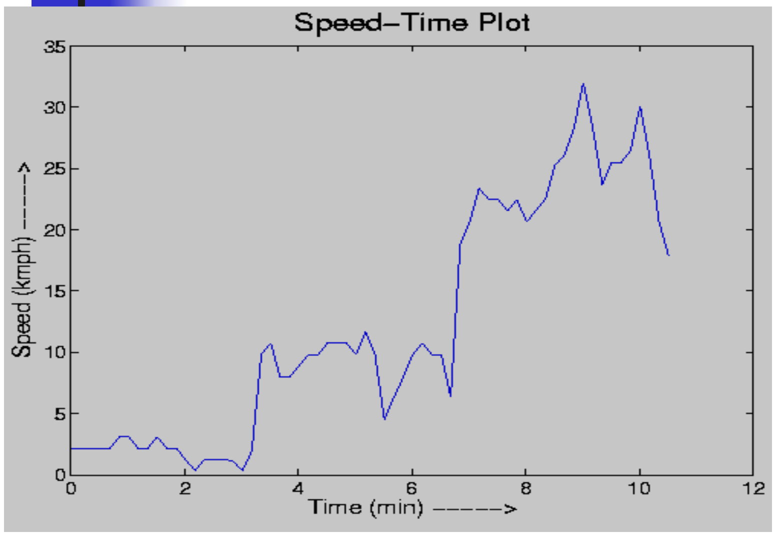
Results – Mobile Performance

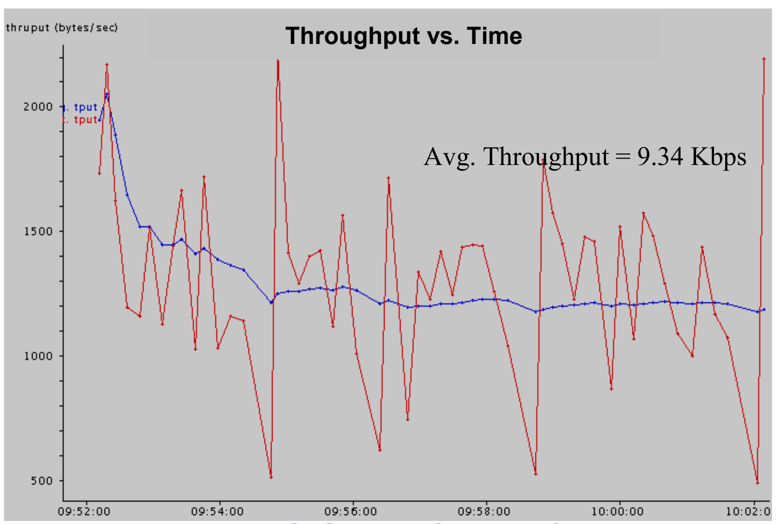


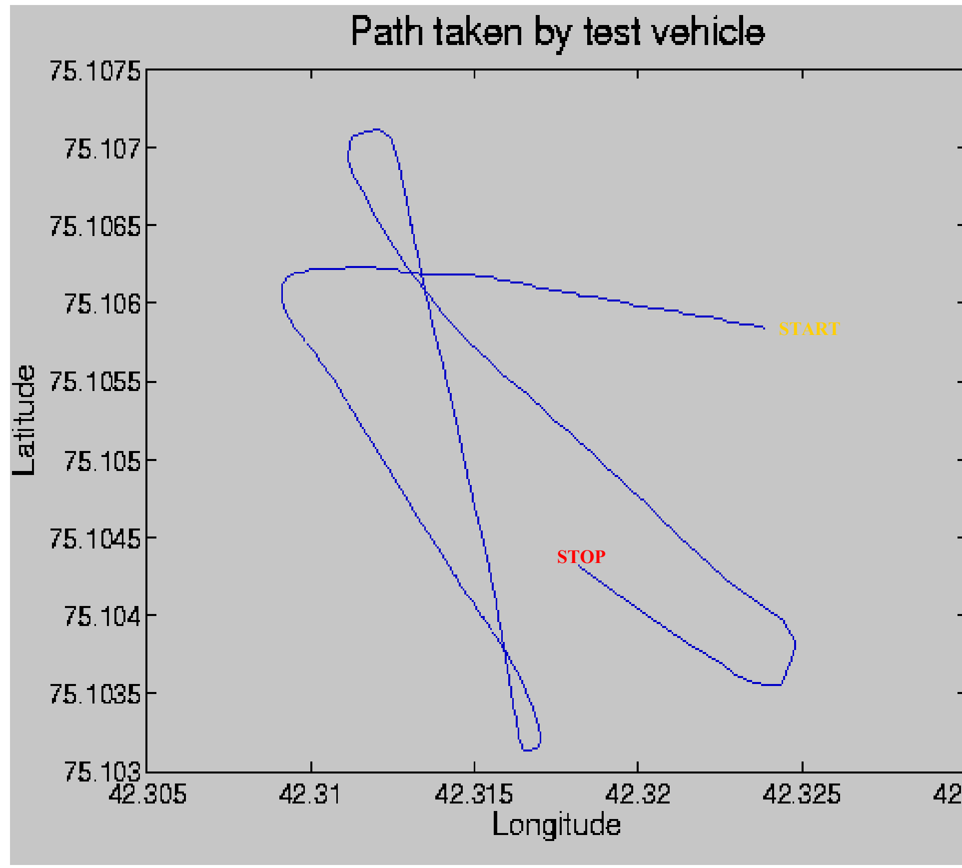




Results – Mobile Performance (cont.d)







Results – Applications

Summer 2003 field experiments

- Software downloads – up to 7.2 Mbps
- Wireless Internet access
- Video conference - real time audio/video
- Video Uploads - Outreach
- General Camp use

Conclusions

- In order to provide data and Internet access to Polar Regions, we have developed a reliable, easily scalable, lightweight, and readily available multi-channel data communication system based on Iridium satellites that provide round the clock, pole-to-pole coverage.
- A link management software is developed that ensures fully autonomous and reliable operation
- An end-to-end network architecture providing Internet access to science expeditions in Polar Regions is demonstrated.
- This system provided for the first time, Internet access to NGRIP camp at Greenland and obtained the call drop pattern.
- The TCP performance and the reliability of the system is characterized

Future Work

- Modify the MLPPP code so that the interface is attached to the bundle and not to the primary link
- Additional research to determine the cause of delay and develop methods to overcome it.
  - Evaluate the new data-after-voice (DAV) service from Iridium
- Evaluate different versions of TCP to determine the enhancements that can handle the random variation and value of RTT
- Improve the user friendliness of the system
  - GUI for connection setup
  - Self-test / diagnostic tools for troubleshooting
- Research into the spacing and sharing of antennas to reduce the antenna footprint

Publications

Conference Publications

- *Iridium-Based Data Communication System Providing Internet Access to Polar Expeditions*, A Mohammad, V Frost, D Braaten, Poster, AGU conference, San Francisco, December 2003.
- *Alternative Communication Networking in Polar Regions*, Abdul Jabbar Mohammad, Nandish Chalishazar, Victor Frost, Glenn Prescott, ISART conference, Colorado, March 2004

Journal Publications

- *Data communication in Polar Regions using Iridium/Wi-Fi Integrated System*, Abdul Jabbar Mohammad, Nandish Chalishazar, Victor Frost, Glenn Prescott, and David Braaten, *to be submitted to* **Journal of Glaciology**

Related Projects

- *Development of Multilink PPP Technologies from Iridium*, Sponsored by Harris Corporation, PI - Dr. Victor Frost

Questions ?? Comments ??