A Full-Scale Ad Hoc Networked UAV Test Bed

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Presented at the
International Symposium on Advanced Radio Technologies
March 2, 2005

Thanks to

University of Colorado
- Brian Argrow
- Cory Dixon
- Jack Elson
- Sheetalkumar Doshi
- Harvey Gates
- Daniel Henkel
- Jesse Himmelstein
- Sushant Jadhav
- Gerald Jones
- Marc Kessler
- Jake Nelson
- Phillip Nies
- Bill Pisano
- Roshan-George Thekkekunnel

Institute for Telecommunication Sciences
- Wayde Allen
- John Ewan

Fidelity-Comtech
- Joe Carey

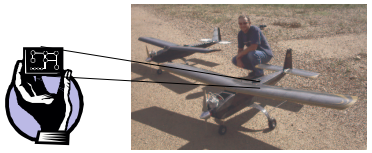
L3-Corporation
- Ken Davey

Air Force Material Command

Overview

- UAVs and the test bed need
- Test bed design
- Results
- Conclusions

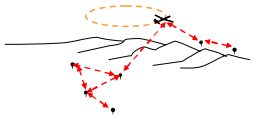
Unmanned Aerial Vehicles (UAVs)



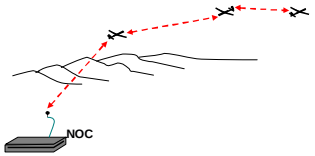
- Small (10kg) Low Cost ($
- Military, scientific, comme

The key to success is robust inter-plane networking

Ad hoc UAV-Ground Networks AUGNets

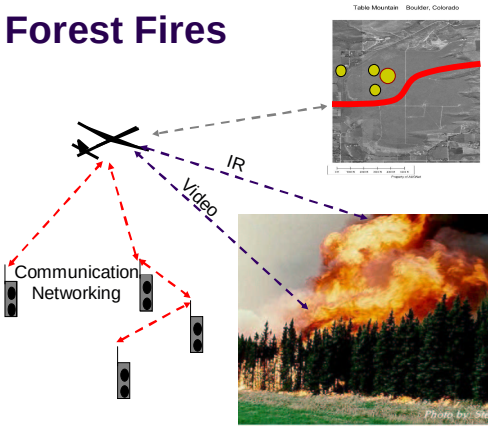


Scenario 1: increase ground node connectivity.



Scenario 2: increase UAV mission range.

UAVs for Forest Fires



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The test bed need

- There is much research in ad hoc networks
  - Mostly simple models or in simulation
  - Test bed work is small-scale, indoor, or limited mobility
  - Some commercial and military deployments
- There is little work on open, full-scale, highly mobile ad hoc networks

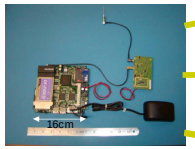
Wireless Test Bed Goals

- Provide a realistic environment
  - Outdoors
  - Full scale
  - Real time
- Collect concise, detailed and accurate test data
  - Embedded collection design
  - Provide GPS time and position of all test elements
    - Terrestrial fixed and mobile
    - Airborne systems
- Make the test bed scalable and transportable

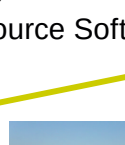
Test Bed Design

Heterogeneous Nodes

- COTS 802.11b (WiFi) Radio Components
- Linux-based Open Source Software
- Small Low-Cost UAV

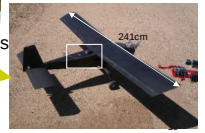


Common HW/SW



Fixed Radios

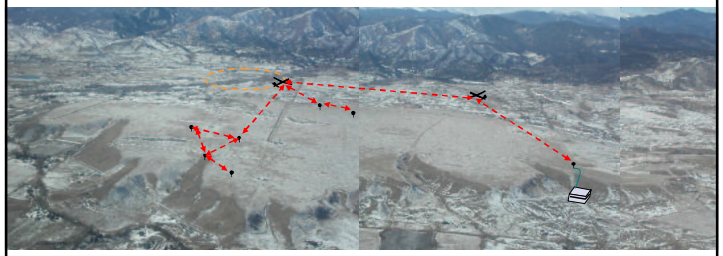
Radios on vehicles



Radios in UAVs

Test Bed Site

Table Mountain National Radio Quiet Zone



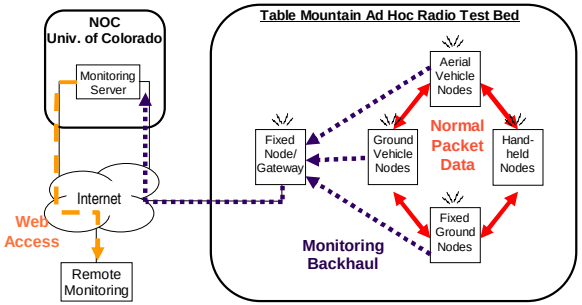
Experimenting to show the effect of the UAV

360° From Center Of Range

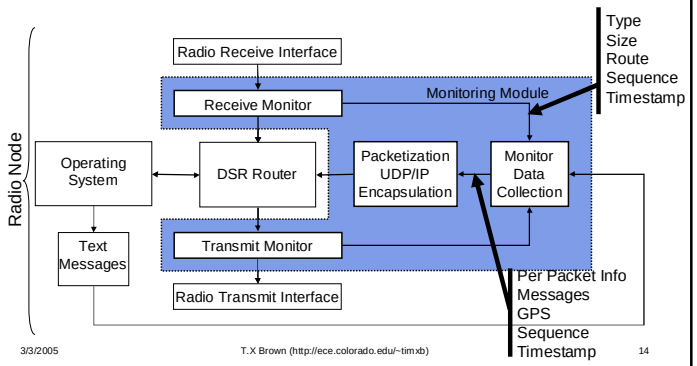
The view looking north

The view looking south

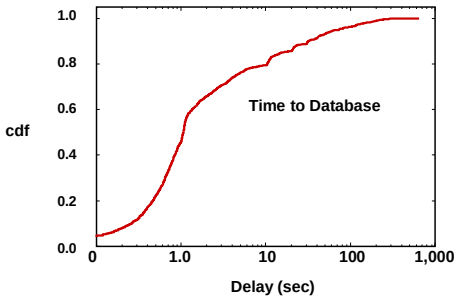
Monitoring Model



Node Monitoring Collection

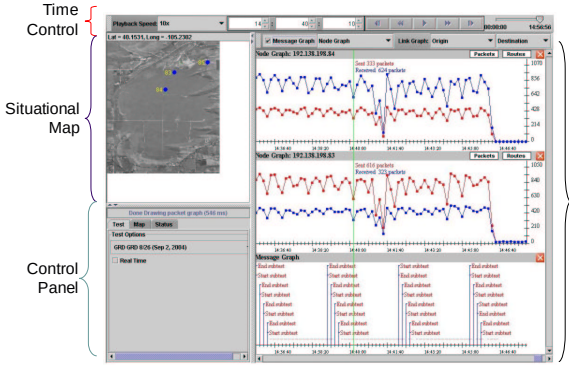


Reliable Backhaul



Cumulative distribution function (cdf), or the fraction of packets delivered within specified delay (sec)

Remote Monitoring



Web-based Java GUI accessing MySQL Database

Testing Metrics

Measures of Performance	Measures of Effectiveness
Data throughput Latency (communication delay) Jitter (delay variations) Packet loss, radio Packet loss, congestion Communication availability Remote connectivity Range	Network self-forming Node-failure recovery Mobility impact Hardware reliability Ease of deployment/transportability Ease of operation Data, voice, Web page communication

Testing Categories

	No UAVs	No UAVs
Fixed	Throughput Connectivity Congestion Subjective	Throughput Connectivity Congestion Subjective
Mobile	Throughput Connectivity Congestion Subjective	Throughput Connectivity Congestion Subjective

Baseline Networks

Typical test bed	Connectivity Subjective

Satellite Connection

Ground-ground	Range
UAV-ground	Range
UAV-UAV	Range Throughput Congestion

Scenario 1: Improved Connectivity

	No UAV	No UAV
Disconnected groups	Node failed	Node failed
Mobile node at edge	Range	Range

Scenario 2: Increased UAV Range

26 Experiments in all

AUGNet Experimentation Work Sheets

Experiment name and reference number

Experiment time and date

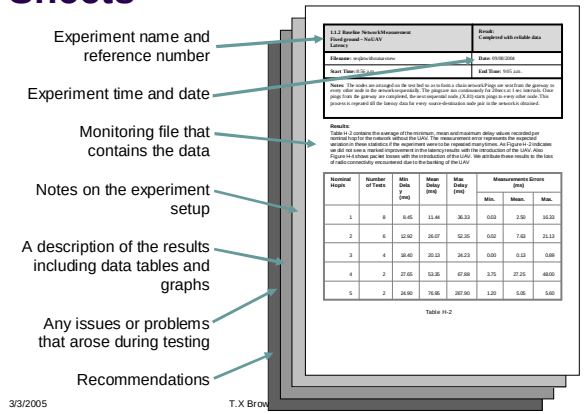
Monitoring file that contains the data

Notes on the experiment setup

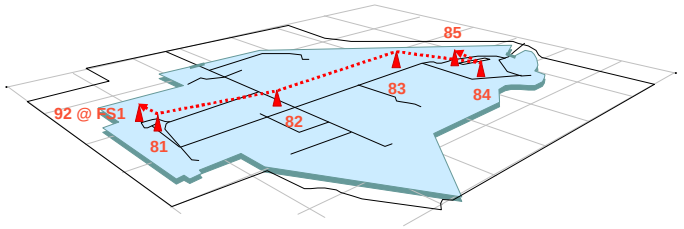
A description of the results including data tables and graphs

Any issues or problems that arose during testing

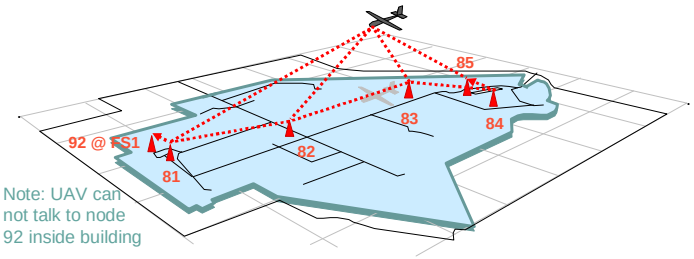
Recommendations



Fixed Ground Sites

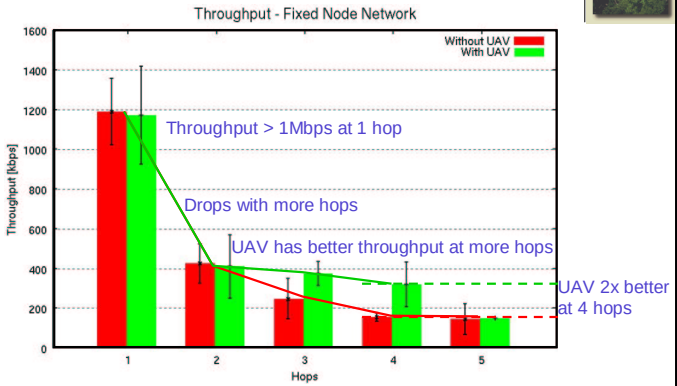


Fixed Ground Sites with UAV

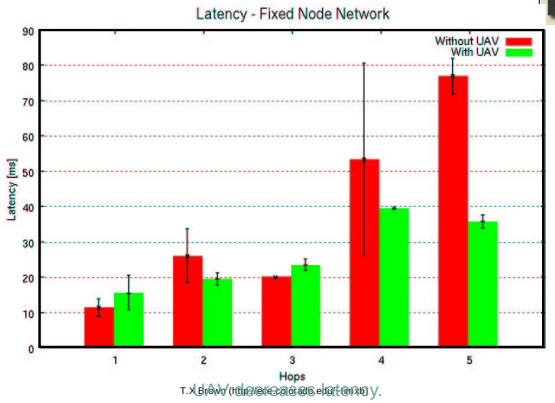


Note: UAV can not talk to node 92 inside building

Meshed Ground Throughput

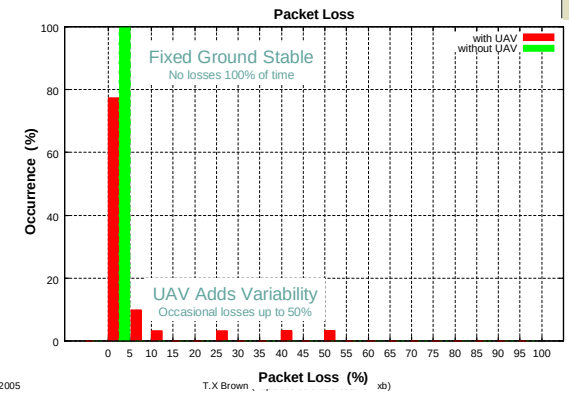


Network Latency

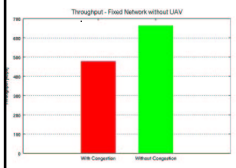


UAV increases latency.

Network Packet Loss



Sample of Meshed Flow Pattern Congestion Throughput Testing



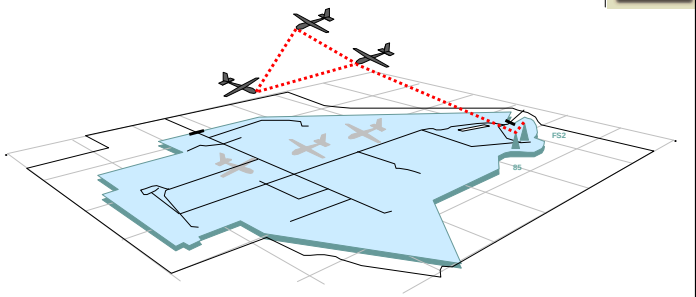
Node Setup / Flow Pattern 92 - 81 - 82 - 83 - 84 - 85	Throughput (Kbps) Without Congestion		With Congestion		Change (%)	
	1170	170	675	125	-42.3	-26.5
	1410	1170	1240	1080	-12.1	-7.7
			1090		-6.0	
	280	200	300	90	+7.1	-55.0
	310	270	110	250	-64.5	-7.4

Unfair!

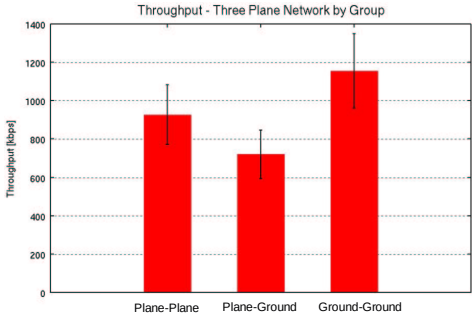
Web Browsing Voice over IP

- Web browsing worked well
  - Can tolerate ad hoc network delays
- VoIP worked well up to 3 hops with fixed nodes
  - Delay and delay variations exceed 100msec.

UAV Swarm



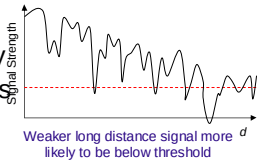
Overhead Meshing: Throughput



UAVs form ~1Mbps network among themselves

Long Range UAV Communication

- UAV meshing over a few km worked well
- Long range did not work
  - 7km could not connect reliably
  - Throughputs zero or 0.01Mbps



- Problem
  - Dynamics + weaker signal = choppy links (have since tuned routing for this)
  - High antenna over residential area sees many interferers (experimenting further)

Conclusion:

- UAV Test bed up and collecting data
- Low Delay, Good Throughput: Can do VoIP
- Multi-UAVS can effectively network
- UAV maneuvering affects performance

Next Steps:

- Coupling Plane Dynamics with Communication
- UAV Flocking
- UAV specific routing
- Security
- NSF ERC

Project website: augnet.colorado.edu