NASA/TM—2006–213479

Wireless Command-and-Control of UAV-Based Imaging LANs

Stanley R. Herwitz
Clark University, Worcester, Massachusetts
Ames Research Center, Moffett Field, California

S. E. Dunagan, D. V. Sullivan, R. E. Slye
Ames Research Center, Moffett Field, California

J. G. Leung
Dryden Flight Research Center, Edwards, California

L. F. Johnson
California State University, Monterey Bay (CSUMB)
Ames Research Center, Moffett Field, California

October 2006

NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM—2006–213479

Wireless Command-and-Control of UAV-Based Imaging LANs

Stanley R. Herwitz
Clark University, Worcester, Massachusetts
Ames Research Center, Moffett Field, California

S. E. Dunagan, D. V. Sullivan, and R. E. Slye
Ames Research Center, Moffett Field, California

J. G. Leung
Dryden Flight Research Center, Edwards, California

L. F. Johnson
California State University, Monterey Bay
Ames Research Center, Moffett Field, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

October 2006

Acknowledgments

The project was sponsored by NASA's Suborbital Sciences Office. Technical support was provided by R. Higgins, M. Aoyagi, R. Billings, B. Gallmeyer, M. Wei, and J. Arvesen. Pathfinder-Plus UAV flight operations were managed by AeroVironment, Inc. (Simi Valley, California).

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-465-

SUMMARY

Dual airborne imaging system networks were operated using a wireless line-of-sight telemetry system developed as part of a 2002 unmanned aerial vehicle (UAV) imaging mission over the USA's largest coffee plantation on the Hawaiian island of Kauai. A primary mission objective was the evaluation of commercial-off-the-shelf (COTS) 802.11b wireless technology for reduction of payload telemetry costs associated with UAV remote sensing missions. Pre-deployment tests with a conventional aircraft demonstrated successful wireless broadband connectivity between a rapidly moving airborne imaging local area network (LAN) and a fixed ground station LAN. Subsequently, two separate LANs with imaging payloads, packaged in exterior-mounted pressure pods attached to the underwing of NASA's Pathfinder-Plus UAV, were operated wirelessly by ground-based LANs over independent Ethernet bridges. Digital images were downlinked from the solar-powered aircraft at data rates of 2–6 megabits per second (Mbps) over a range of 6.5–9.5 km. An integrated wide area network enabled payload monitoring and control through the Internet from a range of ca. 4000 km during parts of the mission. The recent advent of 802.11g technology is expected to boost the system data rate by about a factor of five.

INTRODUCTION

The aeronautical capabilities of UAVs are evolving rapidly, and these platforms are beginning to offer new alternatives for users requiring high spatial resolution imagery delivered in near-real-time [1, 2]. In this context, UAVs are expected to play an expanded remote sensing role that will complement satellites and conventionally piloted aircraft [3, 4, and 5]. An ongoing practical challenge is the development of telemetry capabilities that meet user requirements and are acceptable with respect to cost, data rate, reliability, and ease of use.

This report describes the wireless operation of dual airborne LANs based on COTS hardware configured for imaging system control and data downlink. The telemetry system was built on IEEE 802.11b Cisco Aironet 340 Series Ethernet bridges originally designed for spatially fixed building-to-building linkage. While their use on moving aircraft was not an original intent, this agricultural mapping mission demonstrated their functionality on both manned and unmanned aircraft.

NETWORK DEVELOPMENT AND TESTING

Initial laboratory validation tests were performed at Ames Research Center (ARC) during the summer of 2001. An imaging system LAN was configured to include two high-performance digital cameras linked by Firewire to a rack-mounted Windows PC (dual Pentium 866 MHz, 128 MB RAM) and a Cisco Aironet BR-342 Ethernet Bridge with a 2.14 dBi gain dipole antenna. A base-station LAN included a PC (150 MHz, 128 MB RAM), photo-quality color printer, Internet link, and identical bridge and antenna (fig. 1). The cameras included a Kodak DCS Pro Plus digital camera back (single 4000 x 4000 pixel Bayer mosaic array) interfaced to a Hasselblad 555ELD camera body and lens, and a DuncanTech MS3100 (Redlake, Inc.) multispectral camera containing three 1200 x 1000 pixel arrays. Digital images from both cameras were transmitted through the Ethernet bridges, separated by a distance of 1.5 m, at an effective data rate (including delays imposed by framing, error checking, housekeeping, and re-transmission) of 5.5 Mbps.

Final tests were performed in August 2001 with the imaging LAN deployed on a mountain at 20 km range. The remote bridge was amplified to 1 W and the antenna elevated 3 m from ground level. The ARC base-station bridge was amplified to 100 mW, with modulation DSSS CCK @ 11 Mbps, and antenna positioned 2 m above ground level. Data rates of about 2.5 Mbps were observed, with average signal strength near 40%.

An airborne test was conducted with a conventionally piloted twin engine photo-reconnaissance aircraft in October 2001. The airborne LAN included the Kodak camera and flight computer (166 MHz, 64 MB RAM, OS/2). A 4 dB gain omnidirectional "button" antenna was mounted on the aircraft belly. The ground-based LAN used a dipole antenna (2.14 dBi gain) linked to a Windows 2000 laptop computer (466 MHz, 128 MB RAM). The ground antenna was positioned 3 km tangential to the flight lines on a ridge at 0.3 km elevation. Both bridges were amplified to 1 W (the maximum allowed under FCC regulations) using bi-directional amplifiers with automatic gain control. A ground-based operator controlled camera operation and data downlink using pcAnywhere remote desktop software (Symantec, Inc.). From a flight altitude of 3.1 km and groundspeed of 275-300 km hr^{-1}, continuous broadband TCP/IP connectivity was established between the airborne and ground LANs at distances of up to 17 km. Error-free 16-MB images were transmitted with no data dropouts at data rates of 1-4 Mbps (fig. 2). The flight test validated remote command-and-control of an imaging payload and timely transmission of large quantities of image data to a ground station.

UAV PAYLOAD CONFIGURATION

NASA's Pathfinder-Plus was used for the UAV coffee mission. Pathfinder-Plus is an ultra light-weight flying wing equipped with eight solar-powered electric motors (fig. 3). The aircraft is an enlarged version of the Pathfinder UAV, which in 1997 established a world altitude record (>21 km) for propeller-driven aircraft. Slow flight speeds (generally <50 km hr^{-1} groundspeed) enable the aircraft to effectively "loiter" over localized areas, making this type of airframe potentially suitable for surveillance missions requiring prolonged monitoring within a limited area. For our mission, aircraft command-and-control was accomplished from a ground station located at the U.S. Navy's Pacific Missile Range Facility (PMRF). The payload ground control station was established at the Kauai Coffee Plantation located approximately 20 km east of PMRF.

The imaging payload for our mission consisted of two separate LANs. One LAN was built around the Kodak (K-LAN) for very high resolution imaging, while the other LAN used the DuncanTech (D-LAN) for multispectral imaging. The K-LAN incorporated a micro-EBX motherboard flight computer (700 Mhz, 128 MB RAM) with an integrated drive electronics disk interface, an IEEE 1394 (Firewire) high-speed serial camera interface, and a Windows 2000 operating system. The radio transmission power on this unit was amplified 1 W.

The D-LAN hardware architecture employed COTS components including a commercially available single-board 200 MHz Pentium-class data acquisition computer with on-board SCSI disk controller, and serial devices mated to a PCIMG™ passive backplane. Additional peripheral component interconnect slots expanded the serial communications capacity, provided a dual networking option, and interfaced to a frame-grabber (Imaging Technology PCDig) operating under a custom-developed device driver. A Cisco BR-342 Ethernet bridge was stripped down to board level components and mounted in the D-LAN assembly. The D-LAN data acquisition system employed a customized RedHat Linux operating system. As with the K-LAN, radio transmission power was amplified to 1 W.

Each network included sensor subsystems and a data logger designed to provide metadata for monitoring system health and for use in image geo-rectification post-processing. These subsystems included GPS engines, gyroscopes, accelerometers, magnetic flux gates, temperature and pressure sensors.

The two LANs were configured for remote operation within the UAV's defined weight, volume, and power specifications (Table 1), and housed in lightweight exterior-mounted pressure pods designed to maintain acceptable temperature, humidity, and pressure conditions (fig. 4). The pods, which were extensively tested in environmental chambers, were designed to shield the LAN hardware from the harsh ambient conditions expected at planned mission altitudes exceeding 6 km (e.g., air temperature -20°C). An omnidirectional 4 dB gain "blade" antenna was mounted on the underside of each pod.

PAYLOAD COMMAND-AND-CONTROL

The payload was wirelessly controlled from a ground station established at the plantation. A wide area network was established for aircraft tracking. GPS data collected by a wireless modem receiver within the DuncanTech system were sent by PPP radio link to the aircraft control station at PMRF. These RS232 serial data were encapsulated into IP packets and transmitted over the Internet to the payload control station at the plantation. The packets were then electronically decapsulated, re-converted to serial format, and pointing instructions were sent by wire to two 21-dB gain directional tracking antennas. These antennas were mounted on a single tripod with an azimuth-elevation tracking device (fig. 5). Use of ground-based directional antennas served to maximize link strength while minimizing interference from or to other systems operating in the vicinity.

The D-LAN implemented a robust menu-driven interface for camera control, which involved the transfer of ASCII characters across a 9.6 kbaud radio modem serial link or the Ethernet bridge. The data acquisition program contained subroutines for image assembly, hard disk access, systems health monitoring, quick-look image evaluation histograms, and camera configuration. An algorithm was designed and implemented to automatically trigger image acquisition at prescribed distance intervals along flight lines.

The K-LAN used Kodak Camera Manager proprietary software for image acquisition in either manually triggered or automatically timed mode. The operator interface invoked customized C code to control the flight computer and data logger. As a contingency, the bridge was configured as an "access point" to allow K-LAN access from surface or nearby airborne nodes in the event of payload control station failure. The access point also provided the ability to link multiple ground nodes. These risk mitigation capabilities were ground-tested and used for system maintenance and diagnostic procedures, but were not required during the UAV mission.

A flight simulation was performed in the laboratory during March 2002 to monitor interference during simultaneous downlink from the K and D networks. The two pods were physically separated by a distance 5.8 m, equal to that of the UAV in-flight configuration. The 100 mW bridge output from each LAN was amplified to 1 W and broadcast through the pod antennas. To avoid cross-talk interference, the bridges were operated at opposite ends of the 802.11b frequency spectrum, with the K-LAN set to channel 1 (2.412 GHz center frequency) and the D-LAN to channel 11 (2.462 GHz). A Grasshopper™ wireless receiver detected no radiation leakage from channel 1 to channel 11. However, the transmission profile width of the D-LAN exceeded the 802.11b specification, causing leakage from channel 11 onto channel 1. The interference resulted in marked degradation of the K-LAN effective data rate from 5.5 Mbps to 1.5 Mbps. As a result of this test, a procedural decision was made to instruct operators to avoid simultaneously downlinking on both Ethernet bridges during the mission.

SYSTEM PERFORMANCE

The mission occurred in the National Airspace System (NAS) over the 1400 ha coffee plantation, with a goal of real-time agricultural monitoring. The 30-Sept-2002 flight was performed under the auspices of a Certificate of Authorization issued by the FAA. Takeoff and landing operations were accomplished within special-use airspace of PMRF. The UAV was equipped with a transponder and its flight into the NAS above the plantation was monitored by air traffic controllers located in Honolulu. Total flight duration was 12 hours. Time on-station above the plantation was 4 hours (11:30-15:30 Hawaiian Standard time). On-station flight altitude was 6.4 km above ground level, with groundspeed not exceeding 50 km hr^{-1}. Both cameras performed to specification throughout the mission.

Broadband wireless Ethernet connectivity using TCP/IP was established and maintained between the airborne LANs and the associated tracking antennas. Bi-directional connectivity enabled airborne imaging system control and image data downlink throughout the flight. A total of approximately 50 Kodak and 200 DuncanTech images were acquired, totaling in excess of 2 GB of data. The images were immediately archived onto the respective flight computer disk drives, where they were subsequently accessed and downlinked while the aircraft was on-station. Error-free transmission to identical ground station computers (1.7 GHz, 1 MB RAM, Windows 2000) was achieved at rates of 2-6 Mbps, and statistical mode of 4 Mbps (fig. 6). These effective data rates achieved over a range of 6.5-9.5 km were significantly lower than the link operation speed of 11 Mbps (Table 2), yet still allowed for image download within a reasonable time interval (e.g., about 8 sec for a full DuncanTech scene). Aerodynamic considerations precluded the mounting of relatively bulky directional antennas on Pathfinder-Plus. However, improved connectivity by use of such devices on larger and more robust UAV platforms would be expected to enhance effective data rates.

An Ethernet bridge to the ground-based network with encrypted communication protocols in place allowed for secure payload control over the Internet from areas far beyond the reach of the wireless network. During parts of the mission, for instance, the DuncanTech camera was controlled over the wide area network by a project scientist situated in California (a distance of approx. 4000 km). In this case, the operator was able to monitor aircraft location by real-time GPS readout, evaluate and adjust camera settings to assure optimum signal-to-noise characteristics in the image data, control power to key subsystems, initiate data acquisition, evaluate data quality, and oversee instrument health through critical temperature and pressure data.

CONCLUSIONS

The mission demonstrated the ability of a solar-powered UAV, equipped with downsized imaging systems, to monitor a localized region for an extended period and deliver timely image data. During four hours on-station, the UAV exhibited the ability to navigate pre-planned flightlines, as well as perform spontaneous maneuvers to collect imagery in cloud-free areas. Imagery in this project was ultimately used to map crop ripeness levels, weed outbreaks and irrigation/fertilization problems leading to management decisions that maximize yield and crop value [6].

Wireless 802.11b telemetry established uninterrupted connectivity between two separate imaging LANs and a local ground station. Data downlink was accomplished at data rates that enabled image viewing, enhancing, and printing within minutes of collection. Linkage with a wide area network demonstrated the potential for users to collect customized data in remote fashion, as from the comfort and convenience of their home institution. Since the UAV coffee mission, preliminary tests on our system using more recent IEEE 802.11g bridge technology have shown effective data rates near 25 Mbps, or about a 5x improvement over the 802.11b system reported here.

It is anticipated that UAVs will routinely collect imagery for users responsible for fire management, disaster relief, environmental monitoring, and homeland security [7, 8, 9, 10], in addition to commercial endeavors. The wireless system described in this paper contributes to the evolution of UAVs as near-real-time earth observation platforms. In contrast to satellite-based over-the-horizon systems, which are typically used in longer range missions, 802.11b-based connectivity can offer high bandwidth and low cost options for data delivery to the local user with a minimum of communications overhead. Further, 802.11b (or 802.11g) telemetry may support critical data sharing among airborne nodes under the evolving concept of UAV network centric deployments for scientific and military missions.

REFERENCES

1. DeGarmo, M.; and Nelson, G.: Prospective Unmanned Aerial Vehicle Operations in the Future National Airspace System. Paper No. AIAA-2004-6243, Proc. AIAA 4th Aviation Technology, Integration and Operations Forum, Chicago, IL, September 2004.

2. Herwitz, S.: Coffee Harvest Optimization Using UAV Platforms for the Acquisition of High Resolution Multispectral Imagery. Proc. NASA ERAST Exclusive Preview, Dryden Flight Research Center, NASA/CP-2000-209031, 2000, pp. 49-54.

3. Lawlor, M.: Miniaturization and Networking Pervade Future Unmanned Systems. Signal: Armed Forces Communications and Electronics Association International Journal, vol. 57, no. 8, 2003, pp. 38-41.

4. Peterson, D.; Brass, J.; Smith, W.; Langford, G.; Wegener, S.; Dunagan, S.; Hammer, P.; and Snook, K.: Platform Options of Free-Flying Satellites, UAVs or the International Space

Station for Remote Sensing Assessment of the Littoral Zone. International Journal of Remote Sensing, vol. 24, no. 13, 2003, pp. 2785-2804.

5. Wegener, S.; Schoenung, S.; Totah, J.; Sullivan, D.; Frank, J.; Enomoto, F.; Frost, C.; and Theodore, C.: UAV Autonomous Operations for Airborne Science Missions Paper No. AIAA-2004-6416, Proc. AIAA 4th Aviation Technology, Integration and Operations Forum, Chicago, IL, September, 2004.

6. Johnson, L.; Herwitz, S.; Lobitz, B.; and Dunagan, S.: Feasibility of Monitoring Coffee Field Ripeness with Airborne Multispectral Imagery. Applied Engineering in Agriculture, vol. 20, no. 6, 2004, pp. 845-849.

7. Ambrosia, V.; Buechel, S.; Brass, J.; Peterson, J.; Davies, R.; Kane, R.; and Spain, S.: An Integration of Remote Sensing, GIS and Information Management for Wildfire Detection and Management. Photogrammetric Engineering and Remote Sensing, vol. 64, no. 10, 1998, pp. 977-985.

8. Gubbels, T.: Online Geospatial Information Resources for the Disaster Manager. Proc. 1st International Global Disaster Information Network Information Technology Conference, Honolulu, HI, April, 2000.

9. Hammer, P., Johnson, L.; Strawa, A.; Dunagan, S.; Higgins, R.; Brass, J.; Slye, R.; Sullivan, D.; Smith, W.; Lobitz, B.; and Peterson, D.: Surface Reflectance Mapping Using Interferometric Spectral Imagery from a Remotely Piloted Aircraft. IEEE Transactions on Geoscience and Remote Sensing, vol. 39, no. 11, 2001, pp. 2499-2506.

10. Tsach, S.; Peled, A.; Penn, D.; and Touitou, D.: Civil Applications and Economical Effectivity of Potential UAV Configurations. Paper No. AIAA-2004-6327, Proc. 3rd AIAA Unmanned Unlimited Technical Conference, Chicago, IL, September, 2004.

TABLE 1. PAYLOAD VOLUME, WEIGHT, AND POWER SPECIFICATIONS

LAN	Volume (m^3)	Mass (kg)	Power (W)
DuncanTech	0.05	13	125
Kodak	0.04	17	75

TABLE 2. CISCO LINK OPERATION SPEED VS. DISTANCE, 10 DB FADE MARGIN, 1 W AMPLIFICATION

Mbps	Distance (km)
1.0	28.4
2.0	22.6
5.5	17.9
11.0	11.3

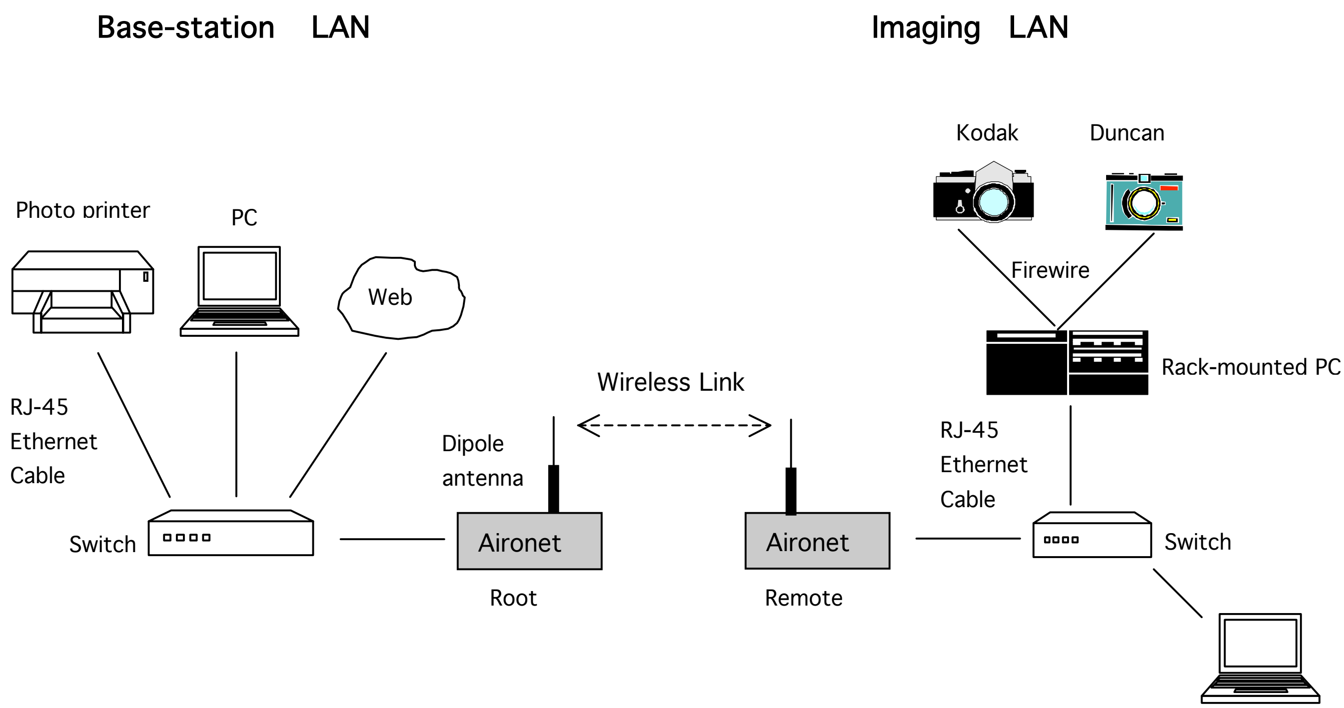

Figure 1. Laboratory network configuration. Imaging LAN linked to base-station LAN by wireless Ethernet. Effective data rates of 5.5 Mbps observed across wireless link.

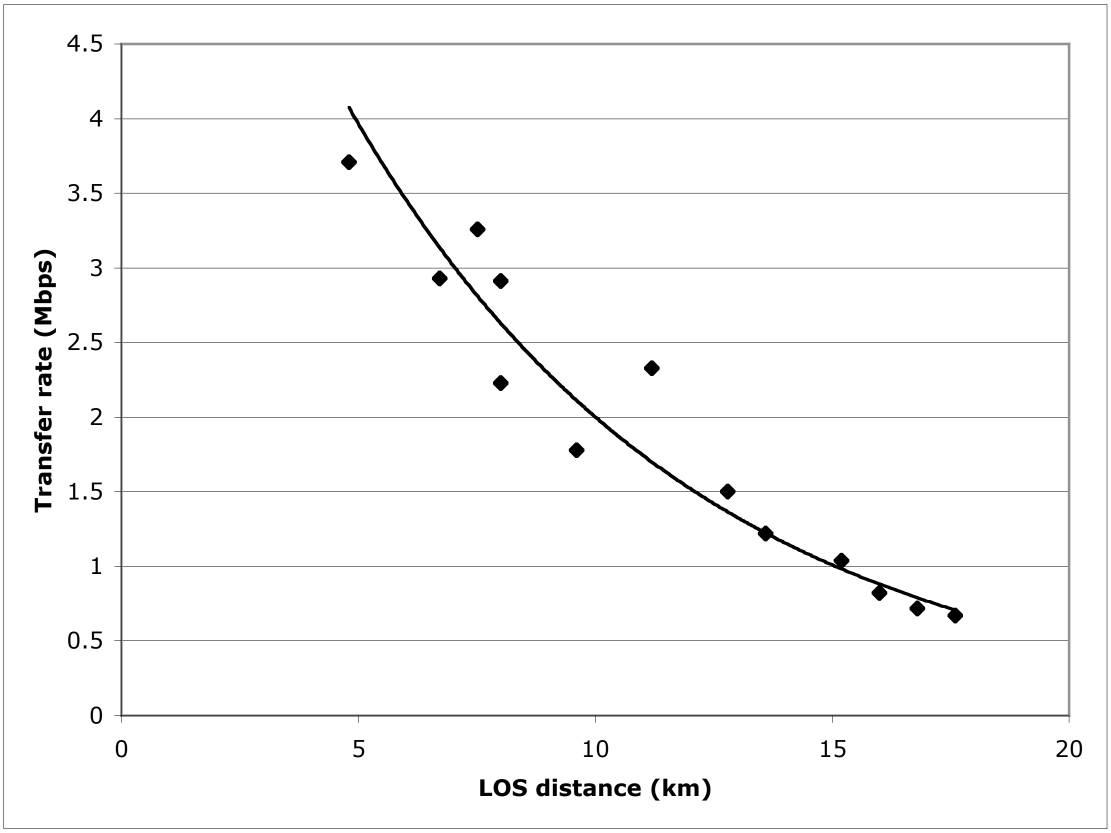

Figure 2. Wireless data rate as a function of line-of-sight (LOS) distance between manned aircraft and receiving ground station, compiled from downlink of several 16-MB Kodak digital images, October 2001 flight test.

Figure 3. NASA's solar-powered Pathfinder-Plus UAV with payload pods visible on underside of central wing section. Each pod is a self-contained LAN – right pod performed high resolution imaging (K-LAN), left pod performed multispectral imaging (D-LAN). At 36.3 m, the wingspan approximated that of a Boeing 737 airliner.

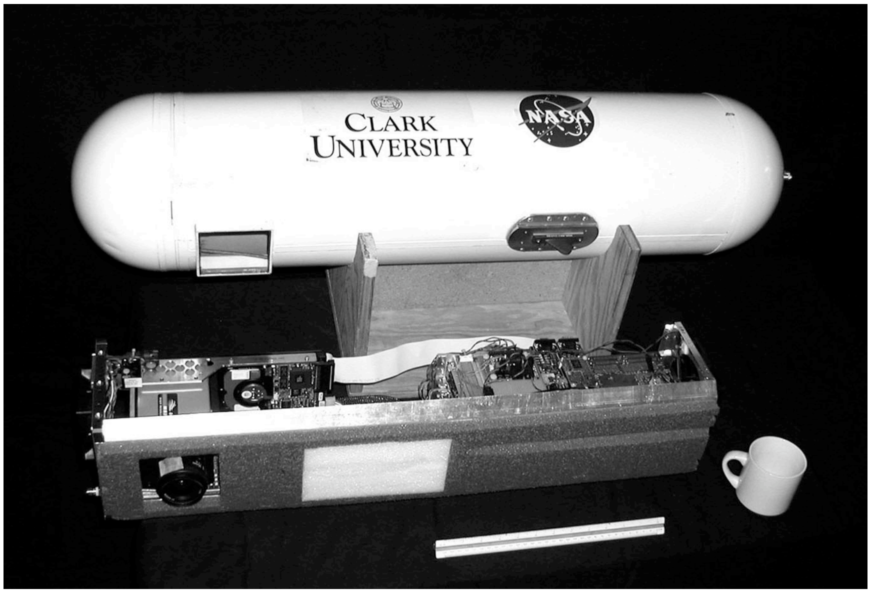

Figure 4. Closeup of D-LAN, with pressure pod in background. Both are shown with underside, which is downward-looking in flight, oriented toward photographer. Omnidirectional blade antenna is positioned on pod belly, just beneath NASA logo. Ruler (30 cm) and coffee cup shown for scale.

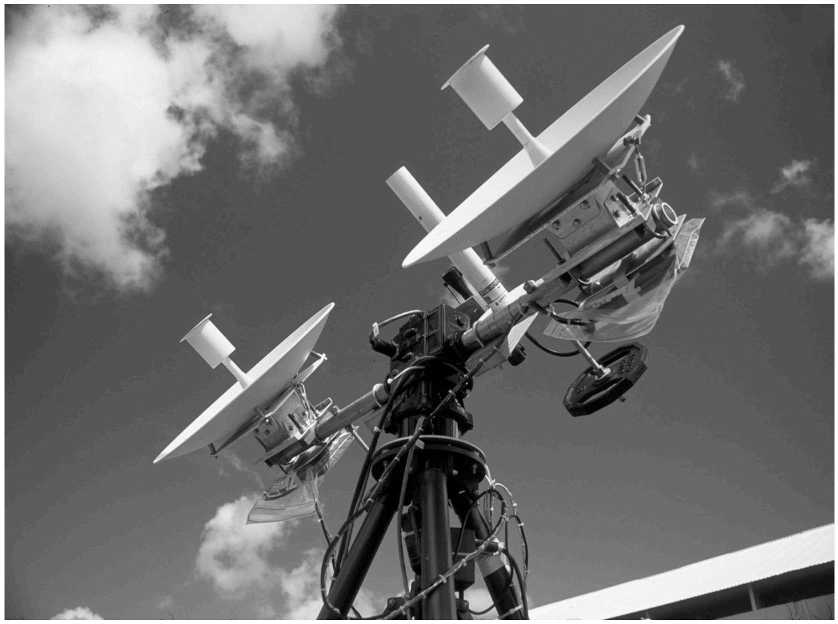

Figure 5. Directional tracking antenna assembly for payload command-and-control. Dishes are dedicated the K-LAN (right) and D-LAN (left). Ethernet bridges are located on the back side of each dish.

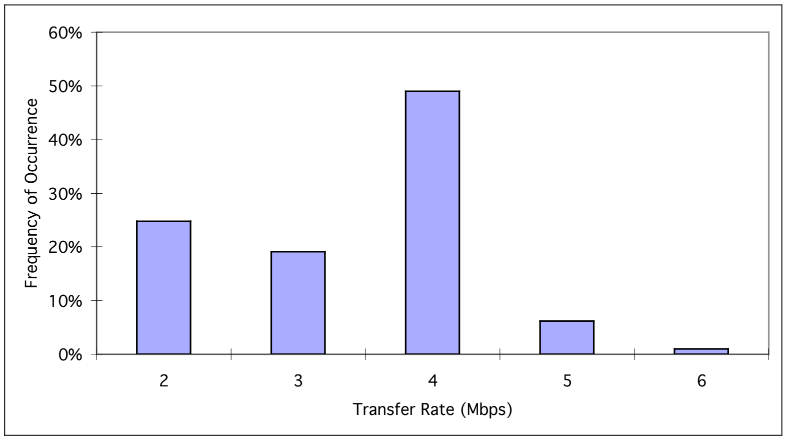

Figure 6. Histogram of effective data rates realized during the 30-Sept-2002 UAV flight, compiled for transmission of 194 Duncan Tech images @ 4 MB each, line-of-sight distance 6.5-9.5 km.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-10-2006	Technical Memorandum	Jan. 2002 - Oct. 2006

4. TITLE AND SUBTITLE	
Wireless Command and Control of UAV-Based Imaging LAN's	5a. CONTRACT NUMBER
	5b. GRANT NUMBER 2N034
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) S.R. Herwitz1, S.E. Dunagan2 D.V. Sullivan2, R.E. Slye2 J.G. Leung3, L.F. Johnson4	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
1. Clark University, Worrester, MA 2. NASA Ames Research Center, Moffett Field, CA 3. NASA Dryden Flight Research Center, Edwards, CA 4. CSUMB, Ames Research Center, Moffett Field, CA	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITOR'S ACRONYM(S)
National Aeronautics and Space Administration Washington, DC 20546-0001	NASA
	11. SPONSORING/MONITORING REPORT NUMBER NASA/TM - 2006-213479

12. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited Distribution: Nonstandard
Subject Category 32, 43
Availability: NASA CASI (301) 621-0309

13. SUPPLEMENTARY NOTES

Point of Contact: S.E. Dunagan, Ames Res. Center Moffett Field, CA, 94035-1000
(650) 604-4560

14. ABSTRACT

Dual airborne imaging system networks were operated using a wireless line-of-sight telemetry system developed as part of a 2002 unmanned aerial vehicle (UAV) imaging mission over the USA's largest coffee plantation on the Hawaiian island of Kauai. A primary mission objective was the evaluation of commercial-off-the-shelf (COTS) 802.11b wireless technology for reduction of payload telemetry costs associated with UAV remote sensing missions. Pre-deployment tests with a conventional aircraft demonstrated successful wireless broadband connectivity between a rapidly moving airborne imaging local area network (LAN) and a fixed ground station LAN. Subsequently, two separate LANs with imaging payloads, packaged in exterior-mounted pressure pods attached to the underwing of NASA's Pathfinder-Plus UAV, were operated wirelessly by ground-based LANs over independent Ethernet bridges. Digital images were downlinked from the solar-powered aircraft at data rates of 2-6 megabits per second (Mbps) over a range of 6.5-9.5 km. An integrated wide area network enabled payload monitoring and control through the Internet from a range of ca. 4000 km during parts of the mission. The recent advent of 802.11g technology is expected to boost the system data rate by about a factor of five.

15. SUBJECT TERMS

Ethernet bridges, WLAN, line-of-sight telemetry, remote sensing, digital imaging

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			S.E. Dunagan
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	13	(650) 604-4560

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18