Tracking Multiple Airborne 802.11b Wireless Local Area Networks to Extend the Internet to Aircrafts in Flight

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ABSTRACT

Wireless local area networks (WLANs) enable the extension of the Internet to aircrafts in flight. To establish this wireless network segment, commercial-of-the-shelve (COTS) 802.11b wireless Ethernet bridges were used. Wireless Ethernet bridges were chosen over optical wireless technology and Internet protocol (IP) satellite modems mainly because of their lower costs, ease and flexibility of implementation. Additionally, 802.11b wireless networks allow a wide range of mobile data devices such as laptop computers and personal digital assistance high-speed wireless access to critical information and applications resided on the aircrafts networks. Since 802.11b WLAN media is shared and traffic generated by other users will degrade the overall performance of the network. With the continual wide spread use of 802.11b WLAN, an aircraft in flight will experience network congestions and poor performance across all the frequency channels. The congestion and poor performance issues can be minimized by tracking the airborne wireless LAN using highly directional antenna and RF filtering. The method of tracking multiple 802.11 wirelesses LAN and the RF subsystem will be described. The applications of 802.11b wireless networks to man and unmanned aircrafts flight research will be discussed.

KEYWORDS

WLAN tracking, 802.11b, UAV, Airborne Internet, Network sensors

INTRODUCTION

To use the Internet as a tool to perform flight research requires a reliable high-speed wireless Internet connection to the aircrafts. Wireless local area networks (WLANs), based on the IEEE 802.11 standard, operate at speeds from 1 to over 50 megabits per seconds. WLANs are also cost-effective and easy to implement. However, one technical problem must be overcome before 802.11 WLAN can use successfully used in aircrafts, that is the interference form other WLAN users located on the ground. In practice, the interference can reach a level that render the wireless LAN useless. One way to reduce interference and congestion is to track the airborne WLANs with highly direction antennas. In this paper we describe a tracking system that can track and maintain reliable high-speed wireless connections to multiple airborne 802.11b WLAN systems and the airborne RF system.

TRACKING METHOD

The method of tracking multiple WLAN radio signals from a moving vehicle is based on pointing an array of directional antennas at the GPS position of the vehicle and adjusts the pointing vector to maximize the signal strength and quality of the WLAN signals.

A wireless modem, operating in the unlicensed 900 MHz Industrial Scientific Medical (ISM) frequency band, provides a serial link between the GPS receiver in the vehicle and the ground computer. The GPS receiver broadcasts NMEA-1083 messages every second at 4800 Baud. A laptop computer calculates the pointing vectors and sends commands to the antenna pedestal. A second laptop computer plots the flight tracks, records the NMEA messages, and monitors the functions of the GPS receiver.

To derive the pointing vectors relative to the local geodetic coordinates of the antenna array, the geodetic coordinates of the vehicle and the antenna pedestal are first converted to Cartesian Earth center Earth fixed (ECEF) coordinates. Equations (5) to (7) in the Appendix show the details of this calculation. The next step is to take the difference between the vehicle and the tracker ECEF coordinates, Equation (4). This step yields a vector pointing to the vehicle in ECEF coordinated. The final step is to transform the pointing vector in ECEF coordinates to local geodetic coordinates of the antenna array in terms of azimuth and elevation angles. Equation (1) and (2) show the details of this calculation. The NMEA message GGA contains the geodetic coordinates required by Equations (1) to (7).

The signal strength and quality of the ground radio is always available on the network. And when the WLAN connection to the vehicle is established, the signal strength and quality of the vehicle radio will also be available on the network. One can then dither the antenna array under software control to optimize the signal strength and quality required for a particular application.

AIRBORNE AND GROUND WLAN SYSTEMS

The airborne RF system is designed to maintain wireless broadband connectivity between multiple airborne networks and the ground networks. To achieve this, an ultra high Q band pass filter first filters the RF arriving at the antenna and rejects other channels in use. After the band pass filter, an automatic gain control (AGC) amplifier amplifies the received signal to increase the received signal strength relative to the background noise. On the transmit path, an AGC amplifier amplifies the output of the WLAN radio and the band pass filter filters and transmits the signal. It is important to use antennas with homogeneous radiation patterns without the overhead null.

All the parameters of the airborne WLAN systems can be accessed and changed in real-time via the network with a Web browser. The center frequencies of the band pass filter can be changed to any of the eleven 802.11b channels, the transmit power to 100 mW, 250 mW, 500 mW, 1 W, and the receive gain to 5, 8, 11, 14, 17 dB.

Ground system is consisted of an antenna array of 24” diameter dishes with a gain of 21 dB and a half power beam width of 12°. The antenna array is mounted on an azimuth and elevation rotor, see Figure 1 and 3.

CONCLUSION

The tracking system presented here can be built entirely with low-cost, commercial-of-the-shelf products. Figure 3 shows the tracking system used by Herwitz et al [3] to establish continuous broadband wireless connections to two networks installed on a solar powered unmanned aerial vehicle (UAV). Figure 3 also shows that the tracking system is quite transportable. The system takes less than an hour to deploy in the field.

While the ground system uses directional antennas to reduce interference from other WLAN users on the ground, the airborne RF system uses high-Q band pass filter to reduce interference. The high-Q band pass filter reduces adjacent 802.11b channel interference. Also the receive gain of the filter is programmable and can be adjusted to optimize the signal-to-noise ratio.

A few radio parameters can affect the running commercial application software written to run on a wired network. They are the distance, RTS/CTS packet size threshold, time to retry, fragmentation size 2048. Setting these parameters to the maximum help prevent excessive attempts to disconnect and reconnect. See Reference (1) for an in-depth explanation to these and other parameters pertinent to WLAN.

UAV flight research commonly requires multiple bi-directional data links that use more complex modulation techniques such as OFMD, 16-QAM, or 802.11g. Since the tracking method is modulation independent, these signals can also be tracked.

REFERENCES

1. Quellet, Eric, Padjen, Robert, Pfunf, Arthur, Fuller, Ron, Thurston, Sean, Blankenship, Tim, Building Cisco Wireless LAN, ISBN: 1-928994-58-X, Syngress Publishing, Rockland, MA, May 2002.

2. Leick, Alfred, GPS Satellite Surveying, 2nd Edition, ISBN: 0-471-30626-6, Wiley, John and Sons, Hoboken, NJ, January 1995.

3. Herwitz, Stan, et al, “Wireless LAN for Operation of High Resolution Imaging Payload on a High Altitude Solar-Powered Unmanned Aerial Vehicle,” Submitted for publication in the Proceedings of the International Telemetering Conference, Las Vegas, NV, October 20-23, 2003.

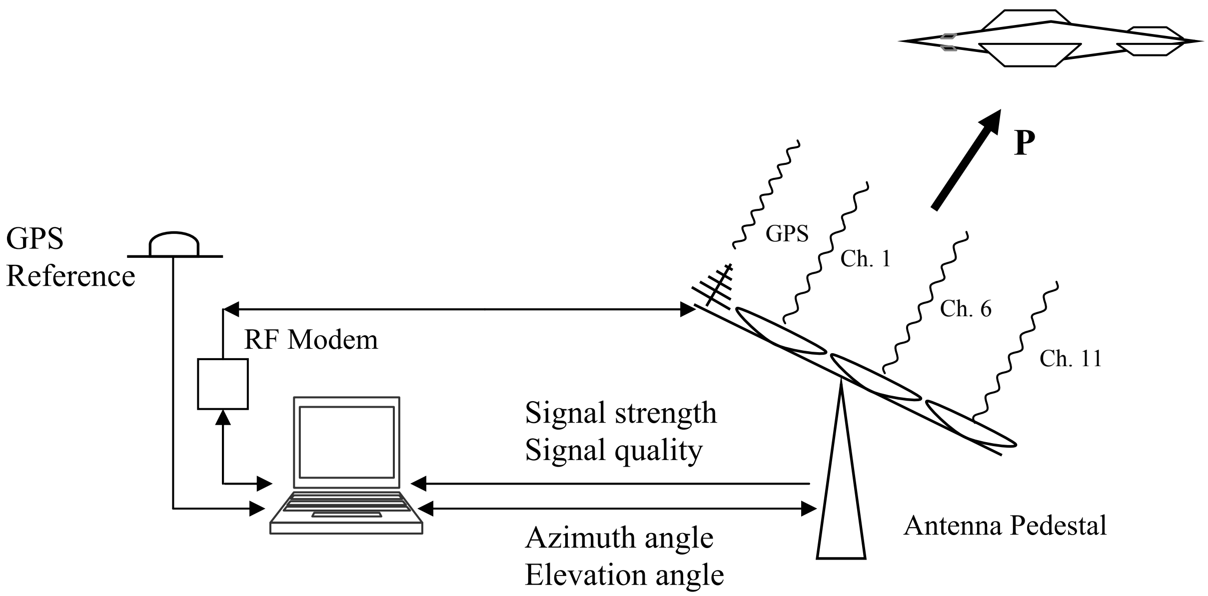

Figure 1. **T**racking multiple 802.11b channels by pointing the antenna array at GPS beacon located on the vehicle.

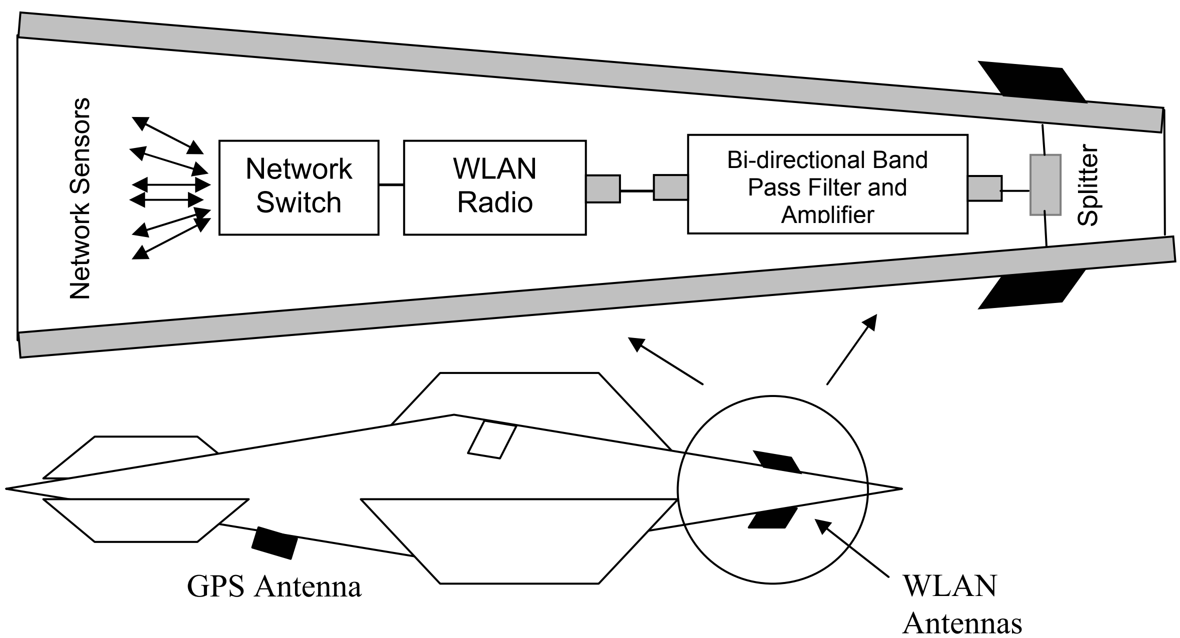

Figure 2. A high-Q bi-directional band pass filter/amplifier module rejects other 802.11b channels and amplifies both receive and transmit gains.

Figure 3. Photo shows an array of 3 antennas. The two dishes are WLAN antenna, one for channel 1, and the other channel 11. The S-Band Yagi antenna is used to receive video from the vehicle. This particular rotor shown here has a rotation range of 450° for azimuth and 180° for elevation; and a rotation rate 6.2°/S for azimuth and 2.7°/S for elevation.

APPENDIX

Az Azimuth angle from the local geodetic north
El Elevation angle above the local geodetic horizon
R Slant range to the vehicle
φ Geodetic latitude
λ Geodetic longitude
h Distance below or above the WG-S84 ellipsoidal surface
a 1234567890 WGS-84 ellipsoidal semi major axis
f 1234567890 WGS-84 ellipsoidal flattening
$_t$ Subscript t indicates values related to the tracker

$$Az = \tan^{-1}\left[\frac{-\Delta x \sin\lambda_t + \Delta y \cos\lambda_t}{-\Delta x \sin\phi_t \cos\lambda_t - \Delta y \sin\phi_t \sin\lambda_t + \Delta z \cos\phi_t}\right] \quad (1)$$

$$El = \sin^{-1}\left[\frac{\Delta x \cos\phi_t \cos\lambda_t + \Delta y \cos\phi_t \sin\lambda_t + \Delta z \sin\phi_t}{R}\right] \quad (2)$$

$$R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \quad (3)$$

$$\Delta x = x - x_t \; ; \quad \Delta y = y - y_t \; ; \quad \Delta z = z - z_t \quad (4)$$

$$x = (N + h)\cos\phi\cos\lambda \; ; \quad x_t = (N_t + h_t)\cos\phi_t\cos\lambda_t \quad (5a), (5b)$$

$$y = (N + h)\cos\phi\sin\lambda \; ; \quad y_t = (N_t + h_t)\cos\phi_t\sin\lambda_t \quad (6a), (6b)$$

$$z = [N(1 - e^2) + h]\sin\phi \; ; \quad z_t = [N_t(1 - e^2) + h_t]\sin\phi_t \quad (7)$$

$$N = \frac{a}{\sqrt{1 - e^2\sin^2\varphi}} \; ; \quad N_t = \frac{a}{\sqrt{1 - e^2\sin^2\varphi_t}} \quad (8a), (8b)$$

$$e^2 = 2f - f^2 \quad (9)$$