AIRBORNE WIFI NETWORKS THROUGH DIRECTIONAL ANTENNA:

AN EXPERIMENTAL STUDY

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In situations where information infrastructure is destroyed or not available, on-demand information infrastructure is pivotal for the success of rescue missions. In this paper, a drone-carried on-demand information infrastructure for long-distance WiFi transmission system is developed. It can be used in the areas including emergency response, public event, and battlefield. The WiFi network can be connected to the Internet to extend WiFi access to areas where WiFi and other Internet infrastructures are not available.

In order to establish a local area network to propagate WiFi service, directional antennas and wireless routers are used to create it. Due to unstable working condition on the flying drones, a precise heading turning stage is designed to maintain the two directional antennas facing to each other. Even if external interferences change the heading of the drones, the stages will automatically rotate back to where it should be to offset the bias. Also, to maintain the same flying altitude, a ground controller is designed to measure the height of the drones so that the directional antennas can communicate to each other successfully. To verify the design of the whole system, quite a few field experiments were performed. Experiments results indicates the design is reliable, viable and successful. Especially at disaster areas, it'll help people a lot.
ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

At present, more and more people are concerning communication in emergency disaster areas. In disaster areas which damaged by earthquake, flooding or avalanche, basic infrastructures like power plants, cellphone base stations and so forth are often out of orders or even damaged as well. In such cases, it's quite helpful if there's a temporary WIFI (Wireless Fidelity) connection from safe areas to such disaster areas [1]-[4]. The cooperation between rescue teams like rescue dogs and rescue robots with control centers will greatly benefit from it. Also, the refugees in such areas can connect with their friends and families by their own smart phones, tablets and laptops as soon as possible to let them know their situation and requirements.

In these years, unmanned aerial vehicles (UAV) technique has been greatly developed [6][7]. The characteristics of UAVs including controllability, high moving speed, self-navigation and all kinds of fail-safe protections make them to be a promising communication solution. Although right now there’re still some considerations on flight time, payload, dynamic communication performance and so on [2],[6]-[8], it’s undoubtable that the UAV WIFI is a fast response internet service provider. In the paper, the feasibility of establishing a WIFI connection by using UAVs and WIFI equipment will be studied to provide internet service to disaster areas.

Considering the cost, compatibility and regulation, the commercial IEEE802.11 WIFI is quite suitable for our drones [10],[11]. People have conducted lots of experiments...
to test their throughput and packet loss by using omni-directional antennas. For example, people tested video transmission between two fixed-wing planes to estimate the feasibility of 802.11n [2]. Their experiments show that the lower throughput and package transmitting rate than theory are a significant challenge for high-mobility airborne wireless transmission. Due to short transmission range of 802.11 (i.e., 100 meters) transmit by omni-directional antennas, directional antennas will be exploited to communicate between drones to increase transmission range and cover range. So far, most experiments are between ground station and drone, obtaining signal by tracking antenna on the ground, or between high speed fixed-wing and fixed-wing [15],[16]. It’s a new attempt to establish WIFI connection between two relatively stable drones in our experiment.
CHAPTER 2
DRONE SYSTEM

Our system is consisted by two identical drones as shown in Fig. 2.1. Each one carries one NANO station antenna for long distance communication to each other, one TENDA A6 for connecting laptops on the ground with NANO station antenna and one ARDUINO atmega328P MCU with barometer and e-compass sensors as shown in Fig. 2.2. For the disaster areas, one drone will be placed at safe area with internet connection and fly the other one directly into the disaster area. After the drone arrives the disaster area, it'll stay in the sky at fixed height for certain period to broadcast WIF (Wireless Fidelity) service to people on the ground. Before batteries die, the drone will fly back to safe area for battery replacement and fly to the disaster area repeatedly. In the experiments, the both drones will fly to same height with different distance to test their communication performance.
Each end of the system will connect a laptop on the ground via the wireless router on the drone. The laptop connected with internet accessed drone will run a performance test software called JPERF [16] operating on SERVER mode; the laptop on the other end will run same software but operating on CLIENT mode. When wireless connection between two NANO stations is established, the performance of the whole network will be tested under two flight status: static and hovering. The test will be initialed from CLIENT side. The CLIENT side laptop will continuously send out data packages to the other side and calculate the response time. Finally, by dividing the size of the data package and response time, the bandwidth of the whole network will be calculated.
2.1 DJI F550 Hexacopter

Fig. 2.3 DJI F550 hexacopter

DJI F550 [17] is a hexacopter designed in 2012 by DJI Innovation as shown in Fig. 2.3. It has six arms made by ABS called PA66 which is a good balance between weight and strength. It uses pre-cut PCB as its upper and lower frames, so power cables and motor speed controllers (ESC) can be soldered easily. The huge space between the two PCB boards and its parallel structure can be used to design our antenna module. In the application of aerial communication, the UAVs should stay in certain altitude for quite long time, so it raises several requirements for UAVs. First of all, the hovering time is quite important. It depends on the capacity of the whole battery system, the weight of the whole UAV, and the affection of the wind. The net weight of the hexacopter is 1600g; antenna is 500g; 3S6600MAH battery is 440g each. In order to increase its payload, the propellers will be upgraded from 8 inch to 10, also bigger brushless motors. Therefore, the whole weight of the UAV with antenna and two 3S6600MAH batteries should be 2980g.
Obviously, at present the Li-ion polymer battery is the best choice. Although right now the weight of our two 3S6600MAH batteries is around 880g, it provides nearly 22 minutes’ hovering time.

2.1.1 Flight Controller: DJI Self-Controller

As shown in Fig. 2.4, the DJI F550 uses NAZA-M Lite self-controller [17]. Even if there’s no any manual operation, the controller can automatically maintain its balance and hover in the air. Because it integrates GPS, 3-axis accelerators, gyros and barometer, it can measure its height, location, heading and speed. This is the main reason why it's applied in the drones. Also, the UAVs are more stable with bigger batteries since the weight is beneficial to eliminate the affection of wind (up to 8m/s or 17.9mph/28.8kmh). At the same time, the stability of the UAVs should be taken into consideration. Currently, the NAZA M-lite flight control system is installed onboard to correct all the flying behaviors to ensure the UAVs and the antenna in an acceptable working range. Because the built-
in GPS, accelerators and gyros, the flight control system can guarantee the UAVs stay at a fixed point without big drifting; at least it won’t be blown away. Based on the onboard GPS navigation, the UAVs can automatically return and land after operation. Therefore, the flight control system can greatly ease the operation of the pilots. Also, LED bars are installed to help observing them even in the night as shown in Fig. 2.5 and 2.6.

![Fig. 2.5. Daylight flying](image1)

![Fig. 2.6. Nocturnal flying](image2)

2.1.2 FUTABA Remote Controller

![Fig. 2.7. FUTABA T9CAP 72MHz Remote Controller](image3)
In our experiment, each end of the drone needs a remote controller to send specific control signal. So a few controllers from different manufacturers like FUTABA, JR and WSKY are compared. Most of them have given up traditional 72MHz communication frequency for aircrafts but shifted to 2.4GHz. Actually in order to eliminate the interference on 2.4GHz which is quite crowded band, they’ve exploited Direct Sequence Spread Spectrum (DSSS) [22] technique to shift traditional high TX power and narrow output frequency to low TX power and wide output frequency. However, to better anti interference, DSSS uses the whole 2.4GHz to transfer its signal. Therefore, it brings great interference to other 2.4GHz devices especially low power level device like TENDA A6 although the DSSS has excellent transmission performance. Finally, the traditional 72MHz remote controller is equipped on the drones. Since the DJI F550 needs ch1: aileron, ch2: elevator, ch3: throttle, ch4: rudder, ch5: switch for GPS/MANUAL/SELF-BALANCE, ch6: switch for Home position record/Heading lock, an at least six channels remote controller is necessary. Considering the compatibility in the future, FUTABA T9CAP controller is chosen as shown in Fig. 2.7. It has 9 channels with 72MHz operation frequency and big LCD screen can display most information for our reference. At present, the system uses ch:45 (72.690MHz) for one drone, ch:37 (72.530MHz) for the other. Theoretically, 72MHz wireless signal won’t influence 2.4GHz antenna part.

For the usage of DJI F550, the controller will control its height and heading by pilots; on the ARDUPILOT side, the controller is only be used to determine the status from AUTO/LOITER/STABLE.
2.1.3 UBIQUITI NANO Station Directional Antenna

![Fig. 2.8. NANO Station Antenna](image)

![Fig. 2.9. Patch antenna structure](image)

In the experiment, two NANO station antennas [18] will be used to communicate to each other remotely. Fig. 2.8 is the UBIQUITI NANO station antenna using in the experiment. They support 802.11g wireless standard and it is a kind of patch antenna as shown in Fig. 2.9. The advantages of patch antenna are good efficiency, compact and easy to produce arrays [24]; however, its disadvantages are directional pattern and narrow band. For the application here, the two NANO stations are used to communicate to each other; therefore, compact size is necessary for UAVs because it means light weight at mean time. Also, the antenna will work on 2.4GHz. Although it can choose 12 channels to work, the frequency range is between 2412-
2467MHz, the characteristic of narrow band will be fine. Furthermore, directional pattern can exploit the main lobe of the signal beam to focus power for further transmission as shown in Fig. 2.10.

![Fig. 2.10. Radiation pattern](image)

The operation manual indicates the transmission range can reach up to 5Km by consuming 12V0.33A4W. The antenna has both 60 degrees on elevation and azimuth with 3dB beam width. So as long as the two antennas are roughly aligned, they can talk to each other. Also, the LEDs on the back of the antennas provide roughly signal strength.
2.2 TENDA A6 Wireless Router

To connect laptops on the ground with NANO antennas on the drones, a wireless router is necessary to connect them together. In order to extend the hovering time for the UAVs stay in the air, the router should be as light as possible. TENDA A6 [19] is the smallest and lightest wireless router at present as shown in Fig. 2.11. It has only half size of a drive license with only 50g’s weight but it supports 802.11b/g/n (802.11n 150mbps). It has a multi-purpose LAN port, the role can shift between LAN and WAN depends on usage. It can choose one working mode from hotel mode, home mode and repeater mode. In the hotel mode, users can connect an Ethernet cable to the socket on the wall to obtain an IP address from uplink router, so the LAN port works as WAN mode. Then, the LAN part (wireless) will broadcast its SSID to other laptops. In the home mode, user can connect an Ethernet cable to uplink devices like a DSL modem or a cable modem. User needs to assign a username/password inside of the TENDA A6 wireless router to make it dial automatically, also the LAN port works as WAN mode. In the repeater mode, the
TENDA A6 wireless router can be set to hook on another wireless device and transfer its internet service to A6’s own connected laptops. Here, the LAN port works as LAN mode, user can connect a laptop by Ethernet cable or wireless to use internet. Here, the repeater mode is chosen to make the Ethernet as LAN to connect wireless part (also LAN).

2.3 ARDUINO and XBEE

To control the heading of the antenna, a ARDUINO board [20] is exploited to read the real time e-compass value and compare it with the desired value, then decide whether drive the antenna or not and its direction. ARDUINO is a kind of very popular hardware developing kit which is based on Atmel Atmega328 chip as shown in Fig. 2.12 and 2.13. It's an 8-bit AVR CPU with 32 Kbytes flash memory, 23 I/O ports, 2 8bit timer/counter, 1 16bit timer/counter, 6 10bit ADC, SPI serial interface and I2C bus. Also there’s an USB port on the board, sketches can be uploaded via USB port, also the data feedback can be monitored via it. For the programming environment, ARDUINO IDE or PROCESSING
can be used here, both are quite easy to understand. It’s not necessary to spend lots of
time, then data can be captured from sensors and drive peripheral devices like LED,
speakers and motors.

In order to transfer information from ARDUINO to ground controller, a XBEE [21]
module will be used to handle it (as shown in Fig. 2.14). XBEEs can be configured as
coordinator, router and end device.

![Fig. 2.14. DIJI XBEE 2.4G wireless module](image)

There’s only one coordinator in one group and it can initially establish a new
wireless network. Then, the group can contain lots of routers and end devices. Sensors
like temperature sensor, dissolve oxygen sensor, PH sensor and so on can be connected
on either routers or end devices. XBEEs inside of one same group can establish a
wireless network. Data from sensors can be transferred from one to another till
coordinator. Also, the coordinator can send data to specified end device or broadcast to
all. The XBEEs work on 2.4GHz and support sleep mode to save batteries. For hardware
configuration, X-CTU is an excellent tool to change any parameters. For example, to avoid
interference with other 2.4GHz devices like TENDA A6, the XBEEs’ channels can be
changed to CH B, the frequency is 2405MHz, equals to the WIFI channel CH 1 as shown in Fig. 2.15, 2.16 and 2.17.
CHAPTER 3

COMMUNICATION SYSTEM

3.1 Overall Communication Network Topology

The overall network topology has been listed as shown in Fig. 3.1. The two NANO station antennas are the main connection of the network. They act as a transparent Ethernet cable to link two ends. On the left end, the TENDA A6 has been configured as repeater mode which means the cable connecting the NANO and the A6’s wireless are working at same LAN mode, so they can ping each other. Any laptops connected with the left A6 can reach the right end of the network. Also, for internet relay, the left A6 can relay an existing internet service and transfer it to the right end of the network. On the right end of the network, the A6 has been configured as a repeater as well. So the NANO antenna works with A6’s wireless together in LAN mode. Therefore, as long as the laptops connected with A6 on the right end, it can visit the internet on the very left.

Fig. 3.1. Network topology
Any laptop on UNT_REMOTE side can ping all the four devices successfully except the internet source (WAN side of internet, LAN can be reached though) because of different network segment. In order to test the whole network performance, all the four configuration interface pages should be logged in simultaneously to check and modify.

In the topology listed in Fig. 3.2, the two TENDA A6 (UNT_CTRL and UNT_REMOTE) and two NANO stations (AP and Station) have four different IP addresses.

![Fig. 3.2. Network topology with IP addresses](image)

Here in this topology, 4 different IP addresses are assigned to all four network devices. Laptops connected with UNT_REMOTE can successfully ping any of the NANO Stations and A6 routers. Because the uplink router UNT_CTRL has connected with internet (uplink wireless router), laptops on the other end can access internet as well. However, the default DHCP inside of the UNT_REMOTE will assign a wrong gateway and DNS (192.168.2.200) to the laptops. In order to access the internet, laptops should use static IP address assignment because the gateway and DNS should be 192.168.2.1 (UNT_CTRL).
3.2 NANO Station Antenna

In order to make two NANO station antennas to communicate to each other, specific configuration are necessary. In our application, one side of the NANO Station antenna should be configured as AP mode, the other one as STATION mode. To configure the first NANO station as AP mode, set local laptop’s IP address to 192.168.1.100 with subnet mask: 255.255.255.0. Type default NANO station address 192.168.1.20, log in by username: ubnt password:ubnt. Then click wireless tab and choose ACCESS POINT from wireless mode, also maximize the output power to 20dBm and data rate to 54Mbps as shown in Fig. 3.3.

![Configuration of AP mode](image)

**Fig. 3.3. Configuration of AP mode**

Next, in order to be found by the other NANO station working on STATION mode, AP’s SSID must be assigned, here it’s UBNT. To avoid interference, the 2.4GHz spectrum has been checked and decide to use channel 11. In the NETWORK option, static IP address assignment is preferred instead of DHCP. Since TENDA A6 is limited in the
192.168.2.X segment, NANO station’s IP address can be modified to fit A6. Here the two NANO station’s IP addresses are assigned as follow:

NANO Station AP: 192.168.1.20 (factory default) to 192.168.2.201

NANO Station STATION: 192.168.1.20 (factory default) to 192.168.2.101

Save all the modification and restart them. From the status of STATION they have established a directly connection (As shown in Fig. 3.4).

Fig.3.4. Status of NANO station in STATION mode

As described in the operation manual, as long as they establish a connection, they just act as a direct cable connection. On the both ends of this cable, two TENDA A6 wireless routers will be linked to connect other devices like laptops.
3.3 TENDA A6 Wireless Router

![Configuration of TENDA A6](image)

*Fig. 3.5. Configuration of TENDA A6*

As discussed above, the two NANO station antennas act like an Ethernet cable. If connect two laptops on each side of the antennas, the two laptops can connect to each other directly just like on one Ethernet cable. Then, the two TENDA A6 wireless routers will be integrated. Network knowledge indicates that in order to smoothly communicate with each other between several network devices, it’s better to put them in one same network segment. If they’re put in same one class C address like 192.168.2.X (X means 1-254), the working mode of TENDA A6 must be configured as Repeater mode as shown in Fig. 3.5. Among five working mode of the A6, only this mode can put wireless side with the Ethernet port together in LAN mode. It means when the NANO is connected with the A6 router by Ethernet cable; it can visit laptops connected by wireless just via the Ethernet port which acts as LAN port. Therefore, if one laptop connected on UNT_REMOTE side
gives a PING command to the other laptop connected on the UNT_CTRL side, it will receive the response successfully.

On the UNT_CTRL side, the router will be configured as REPEATER mode (As shown in Fig. 3.6). If there’s an available internet access point over there like a wireless router or a smartphone with internet connection, the A6 can scan the available SSID and join it. Then, on the A6 another SSID can be created for broadcasting service.

![Configuration of REPEATER mode](image)

**Fig. 3.6.** Configuration of REPEATER mode

LAN port is a part of this service and connects the NANO station antenna. On the UNTREMOTE side, the router should be configured as REPEATER mode as well. But it’s unnecessary to scan and uplink to another available wireless network; it can be assigned an unavailable uplink SSID. Any SSID will be fine just to keep it transparent
between wireless and LAN port. Also, its output SSID can be connected by other laptops, tablets and smartphones.

3.4 Power Supply

![LM2596 DC-DC step-down power supply board](image)

**Fig. 3.7.** LM2596 DC-DC step-down power supply board

For the NANO station antenna, it’s powered by a 3S860MAH (12.6V) LIPO battery since it consumes 12V180mA, so it can be powered by the battery directly. However, both the A6 router and ARDUINO need 5V power supply. After checking Texas Instrument’s power supply chips, LM2596 [25] step-down DC-DC convertor is selected to transfer 12V to 5V as shown in Fig. 3.7. Since its transfer efficiency as high as 80%, it’s unnecessary to worry about the heating caused by traditional power dissipation nor power waste.

In the circuit shown in Fig. 3.8, it’s necessary to precisely adjust the potentiometer VR1 to make the output on 5V. The output current of the LM2596 circuit can reach 3A; therefore, it can supply the A6, ARDUINO board and its sensors much more than enough (See Table3.1).
Table 3.1

Current Consumption

<table>
<thead>
<tr>
<th>Current consumption for 5V circuit</th>
<th>Static (mA)</th>
<th>Dynamic (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TENDA A6</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td>ARDUINO with sensor</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Total</td>
<td>230</td>
<td>230</td>
</tr>
</tbody>
</table>

5V0.23A equals (5*0.23/12)/0.8=0.12A (0.8 is the efficiency of DC-DC circuit)
Table3.2.

12V Power Consumption

<table>
<thead>
<tr>
<th>12V Components</th>
<th>Voltage(V)</th>
<th>Current(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geared motor</td>
<td>12</td>
<td>0.38</td>
</tr>
<tr>
<td>NANO Station antenna</td>
<td>12</td>
<td>0.18</td>
</tr>
<tr>
<td>5V DC-DC circuit</td>
<td>12</td>
<td>0.12</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Considering the voltage of the LIPO battery is keep decreasing from 12.6V till 10.8V, the current consumption would decrease gradually, also the geared motor would work intermittently; the battery life would be 40-50 minutes.

Experiments indicate the 3S860mA LIPO battery can support approximately 40 minutes in the air (See Table3.2). Since the period can cover the time which the UAVs hovering (17 minutes) in the sky, it’s unnecessary to improve the battery life at present.
4.1 Directional Antenna Heading System

In our project, the antenna network system will be integrated together to be a whole part to install on the UAVs. However, the UAVs will drift and swing, sometimes it’ll change location to yield birds. All these external factors will change the direction of the NANO stations. Because the directional characteristic of the antennas, a mechanism is needed to offset such influence on the antenna. The design is based on the reading of an e-compass to calculate its error between current reading and desired direction. The e-compass exploited is LSM303 [26].

![LSM303 e-compass and BMP085 Barometer](image)

*Fig. 4.1. LSM303 e-compass and BMP085 Barometer*

LSM303 is a MEMS device contains magnetometer/compass and 3-axis accelerometer. It supports I2C bus and 3.3V/5V ARDUINO chips. Another advantage of using I2C bus is that another I2C device can be connected in parallel and read them
separately by their unique device IDs. In the design, a barometer is connected (Fig. 4.1) to measure its height, so the two I2C devices can be connected without too much trouble.

All the sketch on ARDUINO board has been developed and tested successfully, but it’s much better if the PCB board can be integrated with the Atmega328P chip, also the XBEE module. If so, the design can simplify the whole structure of the antenna. Therefore, the author designed it on a double-sided PCB by Altium10 and fabricated it as shown in Fig. 4.2.

Fig. 4.2. Design of antenna plate
The following code is used to generate a timer interrupt to transmit information once a second by XBEE.

cli();

TCCR1A = 0; // set entire TCCR1A register to 0
TCCR1B = 0; // same for TCCR1B
TCNT1 = 0; // initialize counter value to 0
// set compare match register for 1hz increments
OCR1A = 15624; // = (16*10^6) / (1*1024) - 1 (must be <65536)
// turn on CTC mode
TCCR1B |= (1 << WGM12);
// Set CS12 and CS10 bits for 1024 prescaler
TCCR1B |= (1 << CS12) | (1 << CS10);
// enable timer compare interrupt
TIMSK1 |= (1 << OCIE1A);
sei();

Transmit information to ground once a second; check whether there's a new degree request incoming at first. Transmit only when there's no incoming request.

ISR(TIMER1_COMPA_vect){
    if (Serial.available()<1){ //If no incoming inf, allow transmitting
        String temp = dtostrf(temperature*100,5,0,buffer);
        String pres = dtostrf(pressure*10,6,0,buffer);
        String alti = dtostrf(altitude*100,5,0,buffer);
        String output = temp + pres + alti;
        output.replace(" ","0"); // Ready for transmission in ISR
    }
Serial.println(output);

Trim compass reading to flat the value by average algorithm.
compass.read();
    float headingRaw = compass.heading();          // Get heading from compass
    if ( headingRaw - outheading > 300){         // Arithmetic to eliminate fluctuating
        diff = (360 - headingRaw + outheading)/2;
        outheading = headingRaw + diff;
        if ( outheading > 359 ){ outheading = outheading - 360;}
    }
else
{
    if ( outheading - headingRaw > 300 ){
        diff = (360 - outheading + headingRaw)/2;
        outheading = outheading + diff;
        if ( outheading > 359 ){ outheading = outheading - 360;}
    }
else
{
    outheading = (headingRaw +outheading)/2;
}
}

float heading = outheading - targetHeading;
// Calculate the module to 360
if ( heading < 0){
    heading = 360 + heading;
}

Finally, the code will judge whether the geared motor should drive the antenna to rotate CW or CCW.

if ( heading < 180 && heading > offsetTol ){
    digitalWrite(motor_cw, HIGH);
    digitalWrite(motor_ccw, LOW);
}
else if ( heading >= 180 && heading < 359.99 - offsetTol ){
    digitalWrite(motor_cw, LOW);
    digitalWrite(motor_ccw, HIGH);
}
else {
    digitalWrite(motor_cw, LOW);
    digitalWrite(motor_ccw, LOW);
}
As in Fig. 4.3, the author uses SANYO NA4S geared motor, it has parameters like these: gear ratio 300:1, 5V120mA 62RPM, torque3300g. The author installed a big gear with 32 teeth to increase the speed since the torque is much more than needed. In order to measure the air pressure to know its height, a BMP085 is used as barometer and also connect it on the I2C bus parallel with the e-compass chip. In the main loop of the sketch, code will keep reading the values from compass and barometer and then send them to ground. Furthermore, to eliminate the influence of the wind brought to barometer, the author cut a small sponge to cover the barometer.

As long as the antenna kit is powered on, the motor will bring the antenna to its initial position: north. Then the Atmega328 will do two things: one is keep the degree of the antenna within the error range of certain degree (E.g. 4°). It mean as long as the reading value locates within the range of 356-4°, the motor won’t rotate. If the reading less than 356°, the motor will rotate clockwise; if the reading greater than 4°, the motor
will rotate counter clockwise. The other one thing is waiting for the desired degree. On the ground controller, if a new degree other than north is selected and sent; the antenna will rotate to this desired degree (E.g. 270°), also will keep in the error range (266°-274°).

4.2 Ground Controller

Before taking off, the NANO station antennas should be aligned face to face to establish connection. When they’re hovering in the air, the two antennas will face to each other to maintain the connection. However, after powering on, both NANO station antennas will automatically face to north by requirement of software default. So the author plans to use a ground controller to adjust the heading degree of the antennas via XBEE modules. Also, the heading degree can be re-adjusted during flight. At the meantime, the controller can display other information like altitude and its battery’s voltage. The author designed the ground controller on a single side board by Altium10 as well as shown in Fig. 4.4

As displayed on the LCD1602’s screen, the current absolute elevation of the antenna is 212m with pressure 98804Pa. If the UAVs fly to 20 meters’ high, the screen will read 232m. To simplify the reading, the author designed a blue button to reset the current elevation to zero before UAVs take off. When it rise to 20 meters’ high, the screen will read 20m. Left value on the screen is the heading degree. User can choose a new degree by adjusting the rotating encoder; when degree is ready, press it and the new degree will be sent to the antenna. Right value is the current battery’s voltage. The circuit
uses 2 LIPO batteries and connected them in serial to get 8.4V. Because the born characteristic of the LIPO batteries, they cannot be over charged or discharged. Therefore, the batteries should be charged by balanced charger to ensure the voltage of each battery won’t exceed 4.2V, also the batteries cannot be discharged lower than 3.6V each, otherwise either over charging or discharging will kill the LIPO batteries forever. So when using the ground controller, user should be aware of the battery voltage should always between 7.2V (3.6*2 in serial) to 8.4V.

Fig. 4.4. Design of ground controller
4.3 UAVs’ Modification

To rotate the antenna part smoothly, two central holes are drilled on both of the upper and lower frames, also two stands with 5mm bearings inside are installed. For the upper frame, a 140 teeth gear is necessary to provide counterforce to antenna part as shown in Fig. 4.5.

At the same time, a 5mm’s diameter steel rod with 65mm’s long is cut to be the spindle of the antenna. Also, one end of the rod was soldered together with the rotating plate. Since the plate is made by double-sided PCB, the rod was soldered from both sides to strengthen the structure. Therefore, when the geared motor rotates on the antenna rotating plate, the gear will engage the big gear installed on the upper frame to generate the counterforce to drive itself rotating. Because the upper gear is not initially designed for the application, so the teeth bring too much torque but lowering the speed. The author will try to find more suitable teeth in the future to get faster rotating response.
Fig. 4.5. Modification of UAV structure
CHAPTER 5

FIELD TEST

5.1 UBIQUITI AIRVIEW2 Spectrum Analyzer

![Image of UBIQUITI AIRVIEW2 spectrum analyzer]

*Fig. 5.1. UBIQUITI AIRVIEW2 spectrum analyzer*

UBIQUITI's Airview2 is a powerful tool which can be used to analyze the signal distribution on 2.4GHz band. It has a compact size makes it look like a flash drive; however, when connecting with a laptop, it turns the laptop to a spectrum analyzer. The Airview2 gathers very important relevant data which operator can analyze and make decisions regarding the wireless networks. Airview2 presents three dynamic data charts; each of which offers unique spectrum analysis. Located on the top is usage view, this view expresses the each channel proportionally according the percentage of frames detected across the spectrum. In the middle is waveform view, this is the power level in function of frequency. In this case, the color correspond the total number of hits. In other words, how many times the RF frames has appeared since Airview2 started. The real time view is located on the bottom which displays power level in dBm as a function of...
frequency. The line color correspond the different measurements include the current energy reading, average energy level and maximum energy signature since Airview2 first begins. Marks can also be set for specific energy frequency to give more detail description for power level at any moment and time. Data can be reset at any time simply click the button on the top right side of the window.

![Fig. 5.2](image)

**Fig. 5.2. Interface of Airview2**

Fig 5.2 is a screenshot took on 12:00PM, 25th Apr 2014 in the 300m’s experiment on the playground. By checking the usage of the Airview2, there’re lots of frames transmitting on channel 1, 2, 3 and 4. In order to reach best transmission result, such channels should be avoided and assign the #1 TENDA A6 (SSID: UNT_CTRL) channel 7 as shown in Fig. 5.3, #2 TENDA A6 (SSID: UNT_REMOTE) channel 9 and #1 NANO
station (AP side) channel 11 as shown in Fig. 5.4. At mean time, #2 NANO station is unnecessary to assign channel because it's working on STATION mode, it'll use the same channel 11 to connect #1 NANO station.

![Fig. 5.3. TENDA A6 shift channel to 9](image)

![Fig. 5.4. Nano station shift channel to 11](image)
5.2 JPERF Bandwidth Tool

JPERF is a free software based on JAVA. It can measure network bandwidth, also it has a graphic user interface to illustrate data. To measure the bandwidth between two laptops, one side is set as SERVER and the other side as CLIENT.

![JPERF's measurement](image)

*Fig. 5.5. JPERF's measurement*

The basic principal of JPERF is that the client send out a package to server and the server acknowledges to the client as shown in Fig. 5.5. The client will calculate the time delay between sending and acknowledging, then divide the package size by delay to get the final bandwidth. It's quite suitable for measuring the bandwidth between two laptops.

For the server side, there is no specific parameter to pre-define. For the client side, server’s IP address, TCP/UDP protocol, theoretical bandwidth and testing duration are necessary to define before performing test. The measurement will initiate from the client,
also the data will be displayed as a chart (as shown in Fig. 5.6) and it can be saved as TXT file for further analysis.

Fig. 5.6. JPERF screenshot

The TXT data will look like this:

local 192.168.2.102 port 55163 connected with 192.168.2.202 port 5001 [ ID]

<table>
<thead>
<tr>
<th>Interval</th>
<th>Transfer</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0- 1.0 sec</td>
<td>802 KBytes</td>
<td>6574 Kbits/sec[156]</td>
</tr>
<tr>
<td>1.0- 2.0 sec</td>
<td>706 KBytes</td>
<td>5786 Kbits/sec[156]</td>
</tr>
<tr>
<td>2.0- 3.0 sec</td>
<td>745 KBytes</td>
<td>6103 Kbits/sec[156]</td>
</tr>
<tr>
<td>3.0- 4.0 sec</td>
<td>712 KBytes</td>
<td>5833 Kbits/sec[156]</td>
</tr>
<tr>
<td>4.0- 5.0 sec</td>
<td>675 KBytes</td>
<td>5527 Kbits/sec[156]</td>
</tr>
</tbody>
</table>
5.3 Real Time Video Test

After measuring the network, a real time video test is performed.

A built-in cam inside of Dell laptop (192.168.2.104) will be used as server (as shown in Fig. 5.7) to broadcast it to ASUS laptop (192.168.2.202) which acts as a client as shown in Fig. 5.8. To implement this, a software called YAWCAM will be tested here.
It will be installed in DELL laptop and open stream port like 5008, then on ASUS laptop open an IE and input DELL's IP address plus port number like: 192.168.2.104:5008, live video appears.

Fig. 5.8. Client side screenshot

5.4 Field Measurement

In this part, field measurements will be performed about the whole system with UAVs and antennas to measure the WIFI performance.

An ASUS N56 laptop with Atheros 802.11B/G/N WIFI card will be connected with UNT_DRONE router and runs JPERF CLIENT mode. Another DELL VOSTRO3550 with Broadcom 802.11B/G/N WIFI card will be connected with UNT_CTRL router and runs JPERF SERVER mode. Because the NANO station antennas does not support 802.11N, TENDA A6 will be configured at 802.11B/G mode. Also, in the JPERF, only UDP will be tested with 54Mbits/S to fit the speed of NANO stations. Since the Ldd in the figure stands
for the distance between two UAVs, the experiments will base on three different distances. The test distances will be 150m, 300m and 1Km static/hovering as shown in Fig. 5.9.

![Fig. 5.9. UAVs in field test](image)

For the flying height, both safe flying and best performance without obstacle will be considered. Here, the Fresnel Zone theory will help as shown in Fig. 5.10

![Fig. 5.10. Fresnel Zone](image)

When a signal is transmitting from one antenna to another, the main lobe of the
signal has certain degree. In order to minimize the interference and maximum the signal-noise ratio, the both antennas should be placed at certain height to avoid obstacle on the ground along the transmission path. In our following experiments, the height will be considered in the flights. Here the formula to calculate the minimum height \( r \) as mentioned in Fig. 5.10 is:

\[
r = 8.657 \sqrt{\frac{D}{f}}
\]

Where:

- \( r \) = radius in metres
- \( D \) = total distance in kilometres
- \( f \) = frequency transmitted in gigahertz.

In the experiments, the distances are \( d_1+d_2=150\text{m}, 300, 1\text{Km} \). Therefore, the calculation of the \( r \) should be:

\[
\begin{align*}
L_{dd}= 150\text{m}, \ r &= 8.657 \times \sqrt{\frac{0.1}{2.4}} = 1.7\text{m} \\
L_{dd}= 300\text{m}, \ r &= 8.657 \times \sqrt{\frac{0.3}{2.4}} = 3.06\text{m} \\
L_{dd}= 1\text{Km}, \ r &= 8.657 \times \sqrt{\frac{1.5}{2.4}} = 5.58\text{m}
\end{align*}
\]

In the experiments of \( L_{dd}=150\text{m} \) and \( 300\text{m} \), the both height are set at 5m. In the experiment of \( L_{dd}=1\text{Km} \), the height are 8m.

For each experiment, the network will be tested 120 seconds 3 times by sending data package from JPERF client side. In static test, the two UAVs are placed 150m/300m/1Km away on the playground and use JPERF to test its throughput. Then,
the both drones will hover in the air, also the throughput will be tested by JPERF. Data has been generated to curves by MATLAB, three colors red, blue and carmine stand for three experiments’ results.

5.4.1 Experiment with Ldd=150m

First, the experiment is performed outdoor at University of North Texas Discovering Park as shown in Fig. 5.11.

![Fig.5.11. Ldd=150 on the playground of UNT Discovery Park](image)

![Fig.5.12. Ldd=150 static/hovering data](image)
From Fig. 5.12, the throughput of the network decreases from static 44Mbits/S to hovering 36Mbits/S. Although the UAVs are supposed to be fixed in the air, but sometime they drift and vibrate caused by wind. In the figure the notches indicate there are lots of delay occurred due to wind interferences, but they are quickly corrected by automatic heading system.

5.4.2 Experiment with Ldd=300m

The 300m experiment is also performed inside of Discovering Park playground as shown in Fig. 5.13. All the parameters are same except the Ldd is changed from 150m to 300m.

*Fig. 5.13. Ldd=300 on the playground of UNT Discovery Park*
The Fig. 5.14 above indicate that by the increases of the distance, the throughput decreases from 44Mbits/S (150m) to 35Mbits/S (300m) when they are static as shown. Similarly, throughput decreases from 36Mbits/S (150m) to 18Mbits/S (300m) when they are hovering. The notch between 61 to 68 second indicates the poor connection between two NANO stations is impacted by big wind and the heading system is quite important to bring the NANO Station to right direction.

5.4.3 Experiment with Ldd=1Km

Fig. 5.15. Ldd=1Km in a ranch in MCKINNEY TX
The 1Km experiment is performed in a ranch of McKinney, TX as shown in Fig. 5.15. The figures show that the static throughput further decreases to 13Mbits/S by the increase of the distance. The average throughput of hovering is approximately 7.8Mbits/S as shown in Fig 5.16. The worst data of the blue curve is captured when the experiment is impacted by continuously huge wind.

![Fig. 5.16. Ldd=1Km static/hovering data](image)

Data shows the drone communication system can reach the throughput up to 7.8 Mbps even under violent situations.
Summary median, average and standard deviation are summarized in the Table6.1. These data indicates that by increasing the distance between two UAVs, the throughput decreases accordingly. Also, the hovering flight brings unstable and fluctuation will impact the performance of the propagation.

In this experiment, the propagation of long distance WIFI signal by using directional antenna and UAVs is studied. Experiment results indicate the application is quite promising especial in disaster areas without WIFI signals. In the areas damaged by flooding, earthquake or avalanche, most infrastructures are damaged; most likely no
electricity, no water supply nor cellphone signal. Also, the road may blocked; therefore, people inside cannot get in touch with outside. Right now, an UAV (controlled by APM GPS waypoints) can be sent to the areas to provide WIFI service. People inside can use their smartphones or laptops to communicate with outside world to notify their situation and get help. At the meantime, rescue teams with dogs and robots can use WIFI to improve their efficiency. Actually the drone WIFI system has successfully integrated with dog rescue team and robots rescue team from other universities already for quite a few times.

Because the throughput is associated with the precise heading, the heading mechanical system will be further improved to enhance the heading responding. Also, automatic signal searching will be considered and added into next design. On the UAV part, since at present the hovering time is limited within 20 minutes, a new design will extend it up to 40 minutes to meet the practical requirements.
REFERENCES


