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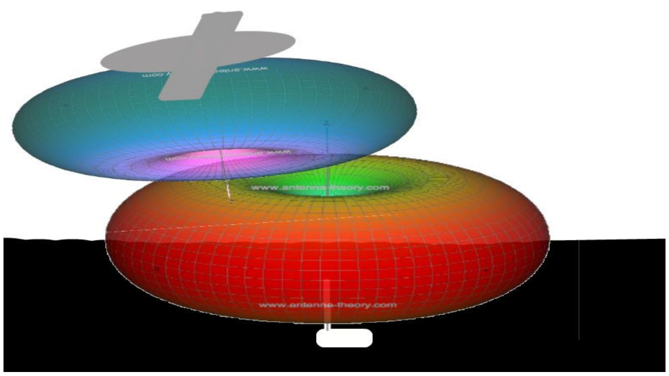
Simulating a Wireless Communication Network Across Autonomous Systems

1. Objective

The ultimate goal of the project is to generate a statistical model from a representation of a system that measures the mean value of the signal/noise ratio with variance based on the pose of a ScanEagle relative to a fixed ground node. In other words, design a simulation that accurately replicates the processes of a ScanEagle wirelessly communicating between fixed ground nodes via radio signals.



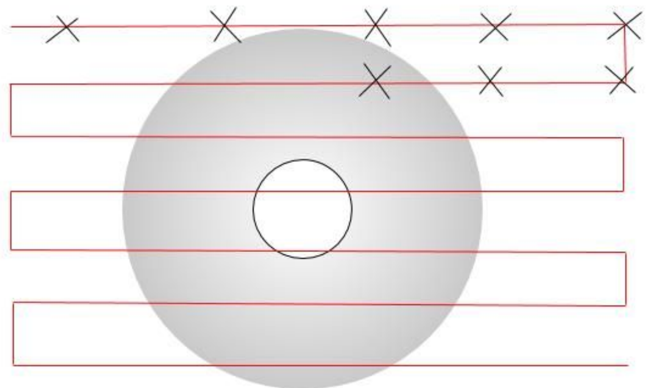


Figure 1: UAV antenna field in contact with ground node

Figure 2: Aerial View of proposed UAV orbit

Methodology:

The simulation can be effectively broken down into a simple input-output function.

Inputs: Consist of the physical components of the system as well as the characteristics associated with them.

1. ScanEagle (variables change)
    a. State vectors/pose (x, y, z, ϕ, θ, φ)
        i. Position is determined with GPS, orientation is determined with IMU
2. Ground Node Antennas (variables constant)
    a. Antenna design (signal pattern, fresnel zone)
    b. Radio power (2W, 5W)

Function: There are, but not limited to, two approaches to generating an output from the inputs depending on what resources are available.

1. If actual data from previous ScanEagle trials in an identical situation is available, an output could be easily generated by matching the components in simulation to the trials and outputting the SNR value for that particular ScanEagle pose.

2. If there is no actual data, the behavior of the ScanEagle and radio signals of both the ground and aircraft nodes would have to be estimated with physics equations, eventually returning the SNR values.

Note: Proportions of both methods can be used to ensure the most accurate representation of the output.

Output: Signal to Noise Ratio

By pairing SNR to coordinates in a local or actual map, we can make a realistic statistical model for which a ScanEagle can navigate through.

Note: SNR is inversely proportional to distance.

As a result of the input/output model, our system can be represented by the following function.

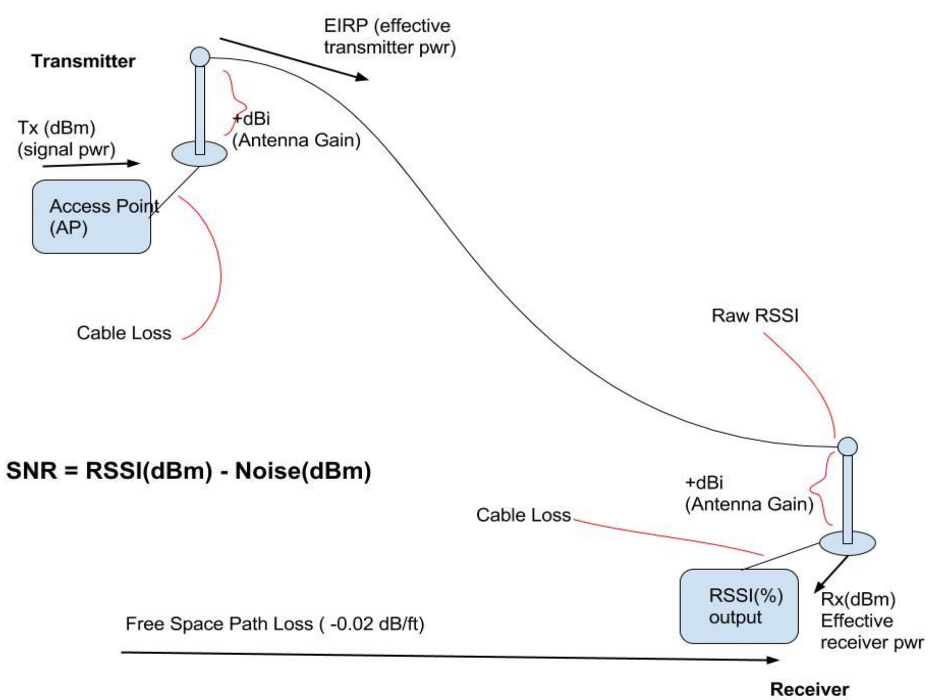
SNR = f(UAVx, AGx) Where UAVx = ScanEagle's state vectors
AGx = Ground Antenna's power and design

2. Research/Project Breakdown

Antenna Simulation and Applications:

In simulating an antenna, several general concepts were broken down about common antennas that we could then replicate through theoretical models and data collection.

Figure 3: Characteristics of Radio Transmission



Basic Antenna Concepts

Signal(RSSI):

- Measured in dBm from -120 to 0
- The more positive the number, the stronger the signal.
- Usual range is from -87 to -45 db.
- Affected by Access point transmit power, antenna, client's antenna
- RSSI value is pulled from the receiver/client side, therefore not the same as transmitted power from transmitter(EIRP).
- EIRP(Transmitter's effective power) (dBm) = AP's signal power(dBm) + Antenna Gain(dBi)

$$RSSI(dB) = (EIRP - 0.2(Dist\ from\ Antenna)) + Antenna\ Gain$$

Noise:

- Noise is all other aspects besides the expected signal.
- Includes thermal, light, white, conflicting signals
- Contributes to loss of expected signal
- Measured from -120 to 0 dBm, where the more negative, the better the conditions; less noise interference.
- Varies at locations depending on environment.
- *Note: Not able to collect noise data from Cavr ThinkPad Laptop*

Signal to Noise Ratio:

- Due to the logarithmic nature of decibels, the ratio between signal and noise is calculated with a subtraction sign.

$$SNR = Psignal(watts)Pnoise(watts)$$

$$SNR(dB) = Signal\ Value(dB) - Noise\ Value(dB)$$

Link Quality:

- Overall process by which measurements of signal quality are made, assessed, and analyzed.
- Created by assessing link parameters such as bit error ratio, Throughput, packet error loss, and SNR.
- Usually a value denoted as a percentage between current link and best possible link.

Note: Link quality was a better suited measurement for us because it included multiple significant variables present in our testing environments. We approached our testing with a goal of finding our own link quality metric based on data from parameters.

IEEE 802.11 Specifications:

802.11 is a set of specifications that controls the access and physical parts of wireless local area networks at a variety of frequencies/bands. The IEEE releases versions of specifications called protocols, each with their own characteristics and advantages. (802.11 a,b,g,n,a,c,d, etc.)

Common protocols

- 802.11a (OFDM waveform): 5.8 GHz, 1.5 to 54 Mbits/s
  High carrier freq. More absorbed through objects, lower range. Less crowded than popular 2.4 GHz.
- 802.11b: 2.4 GHz, 11 Mbits/s
  Low price, very common wireless protocol. Interference from crowding and appliances such as microwaves.
- 802.11g: 2.4 GHz, 54 Mbits/s
  Backwards compatible with 802.11b. Very high throughput.

Current Applications:
Goal: Creating an accurate model of Persistent Systems MPU4 Antenna's link quality as a function of distance with theory and lab data.

System Setup: Wave Relay Wireless Mesh Network
A more complicated network that includes multiple nodes programmed to create a larger network.

- Information "hops" from one node to next instead of traditional transmitter and receiver.
- Nodes automatically choose quickest and safest path to transmit, called Dynamic Routing.
- Advantages include:
  - No need to connect many access points to ethernet.
  - Adjustment of nodes to self-heal network.
  - Useful for no-line-of-sight situations.
  - Seamless connection between nodes, constantly searching for best connection.

Software of system: Simple Network Management Protocol (SNMP)

- Internet standard protocol for collecting and organizing info on IP networks. Typical usage of SNMP involves administrative computers called managers tasked with monitoring/managing groups of devices/agents on a network. Each system executes software component called an "agent" which reports to the manager.
- Protocol data returned includes IP header, Throughput, Bit-rate error, Packet loss, Response Time, SNR
- Currently a javascript system that outputs data to parsable text files.

Our pursuit of link quality at NPS involved using Wave Relay technology, a 2.4 GHz wireless mesh networking system between two Persistent Systems MPU4 antennas with SNMP monitoring software.

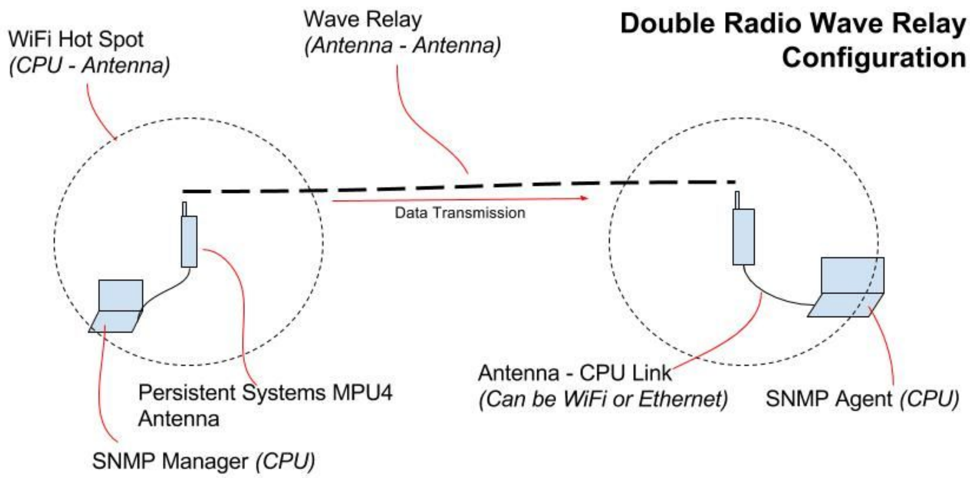


Figure 4: Model and characteristics of the experiment

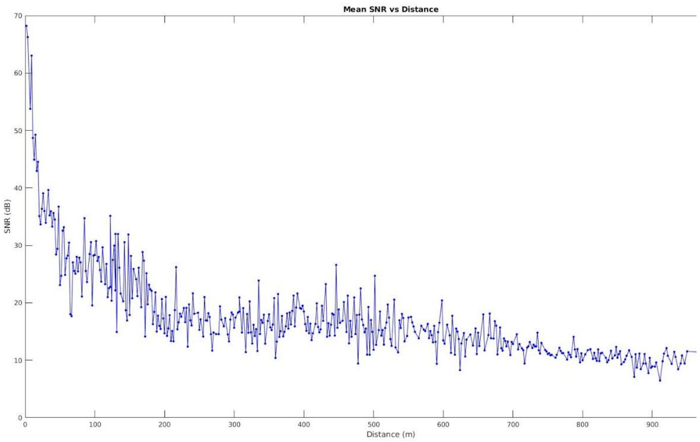
Data Collection:

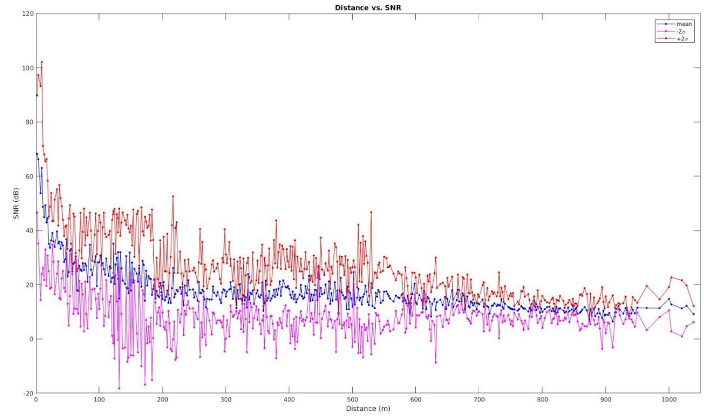
To measure the parameters of link quality (SNR, Throughput In, Throughput Out, Response Time, and Packet Loss) as a function of distance, we set up the SNMP manager with an antenna at one static waypoint. Then, the distance between the manager and agent systems were steadily increased over time with the aid of GPS. During the entire process a 1.1 GB file was being transferred from the manager CPU to the agent CPU through the antennas.

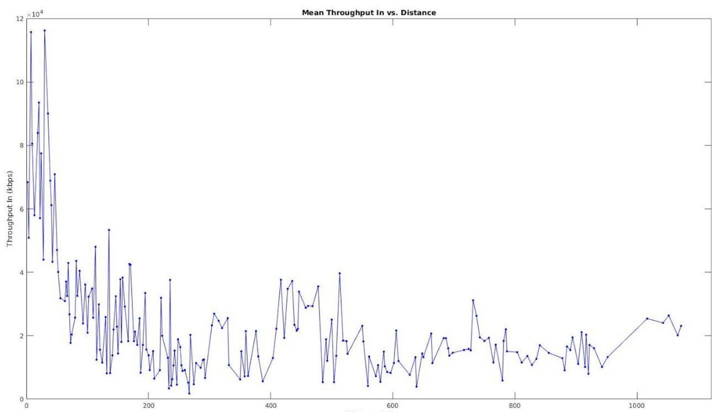
On the agent computer, several scripts were run to record the parameters, as well as distance.

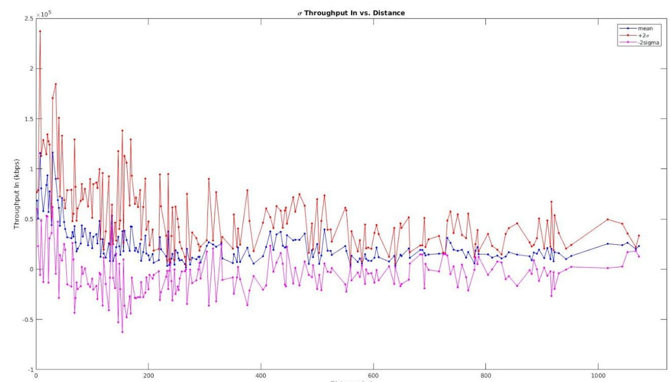
- SNMP Poller: A javascript file recording the throughput in and out, response time, and packet loss of the connection between the CPUs during file transfer with a timestamp at every 10 seconds. Outputs to text file.
- WLAN0 Poller: A bash file that parses the bash readout from *iwconfig* Linux command and returns the RSSI between the computer and antenna and timestamp at 2 second intervals. Outputs to text file.
- Distance Poller: A python script that records longitude, latitude, distance from waypoint, and timestamp at 2 second intervals. Utilizes pynmea to read and parse the GPS NMEA serial output from a Garmin GPSmap 76s device. Outputs to text file.
- Combination parser: A python script that obtains the values from each parameter script and syncs them all according to timestamp. Generates a master data set text file that can be imported into MatLab and analyzed.

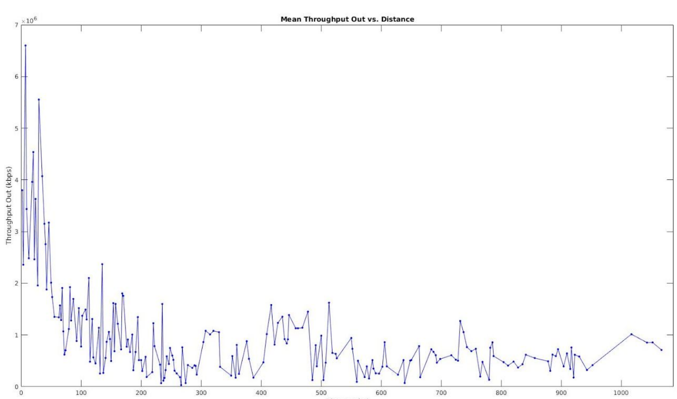
10 trials were conducted at Del Monte Beach in Monterey.


Mean SNR vs Distance
SNR (dB)
Distance (m)


Distance vs. SNR
mean
-2σ
+2σ
SNR (dB)
Distance (m)


Mean Throughput In vs. Distance
Throughput In (kbps)
Distance (m)


σ Throughput In vs. Distance
mean
+2σ
-2sigma
Throughput In (kbps)
Distance (m)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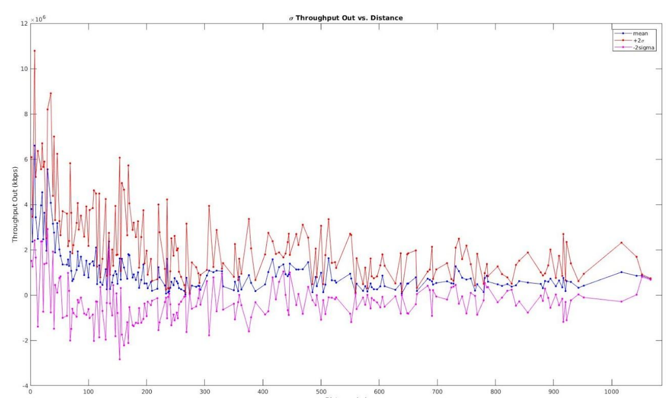
σ Throughput Out vs. Distance
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+2σ
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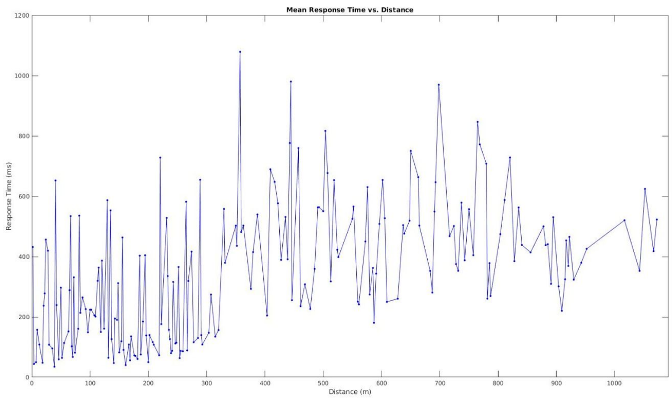
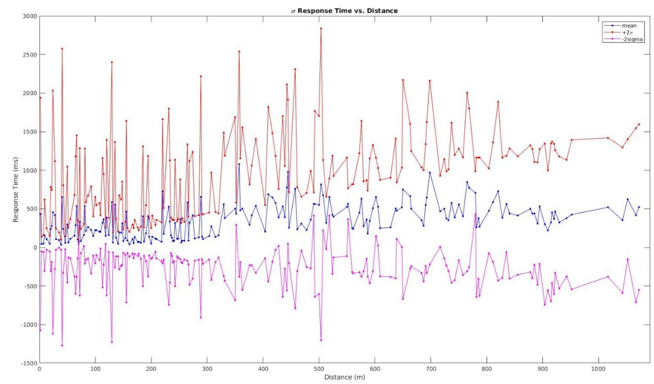




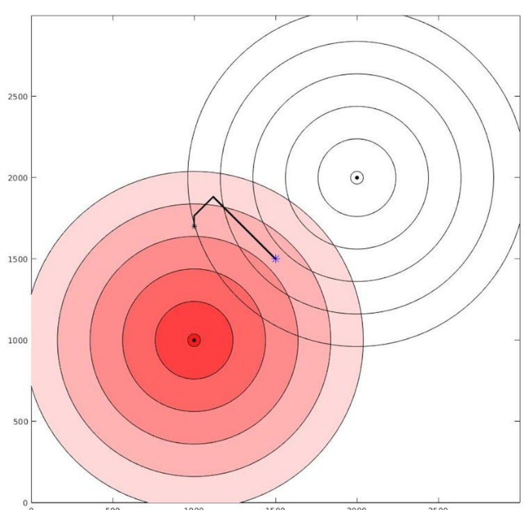
Scan Eagle Simulation:

The UAV travels at a linear speed of 45 km/h and has a linear roll to radius ratio given by the following equation. $$Radius = -69.44 \cdot \phi + 819.44$$

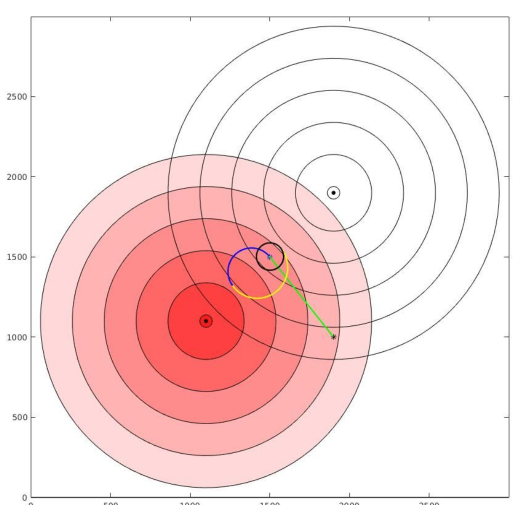
Maximin Model: Our current simulation calculates the position of best SNR (optimal position) based on the sum of the SNRs between the two nodes. However, there are issues with this method because it does not take into account the quality of node connection separately, so if UAV were to be positioned in a signal overlapped area very close to a node, the strength of the node itself would overpower the SNR of the actual optimal location.

Implementing Dead Reckoning: After seeking the optimal position, the simulation has to emulate the behaviors of a ScanEagle aircraft. This was done in the simulation using counter-clockwise rotational matrices, and navigation by roll and heading rate.

(Aerial Views of 3000 sq m. grid with UAV proceeding to optimal position between two ground nodes.)



Before Implementing Dead Reckoning



After Implementing Dead Reckoning

PID Control: The simulation is heavily reliant on proportional–integral–derivative control (PID), which utilizes feedback control algorithms. Based on sensory input, SNR for example, the controller can compare the input to a desired value of SNR. Based on the difference between the two, the controller can send a command to the plant, which carries out a physical action resulting in an output closer to the desired goal. The sensor then reevaluates the environment and submits another input to the controller, where the entire loop repeats until the desired value is reached. The outcome of the feedback loop can be represented by the following equation.

$$X = A\overline{x} + Bu$$

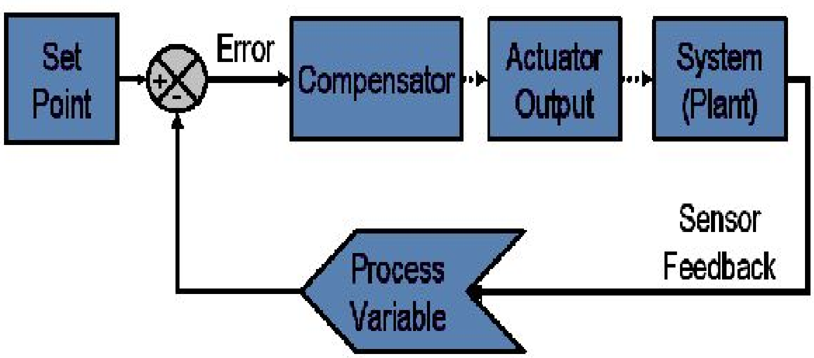
Where X is the continuous rate of state change, A is a scalar proportionate matrix, $\overline{x}$ is the current state matrix, and Bu is the controller modifying matrix.

Meanwhile, the output of the plant is represented by,

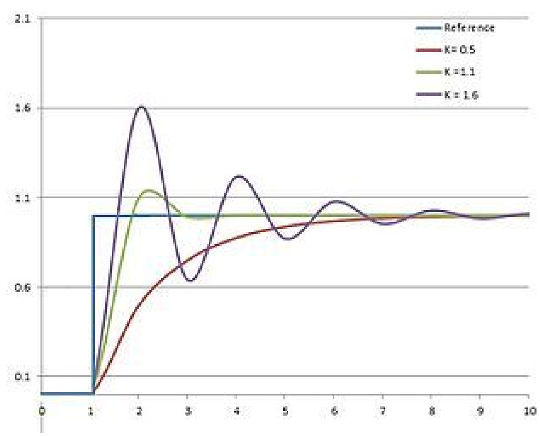
$$Y = C\overline{x} + D$$

Where Y is the generated action of the plant, C$\overline{x}$ is the proportionate state matrix, and D is the modifier matrix.

Common applications of this algorithm within this system includes the maximin search for optimal position between the two nodes. In addition, PID control is used on the flight computer of the UAV to adjust speed and other parameters within the constraints of the vehicle dynamics, all linear time-invariant processes.



Closed feedback control loop.



Possible control routes with varying efficiency.

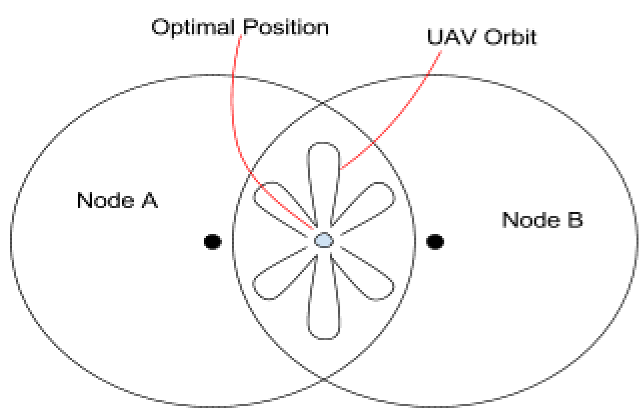
3. Conclusion and Future Steps

This paper described the components of antenna signal fields and UAVs for a simulation designed to create an optimal UAV orbit among several ground nodes. We've contributed to the creation an accurate link quality algorithm that can gauge and act upon the characteristics of gathered antenna signal data.

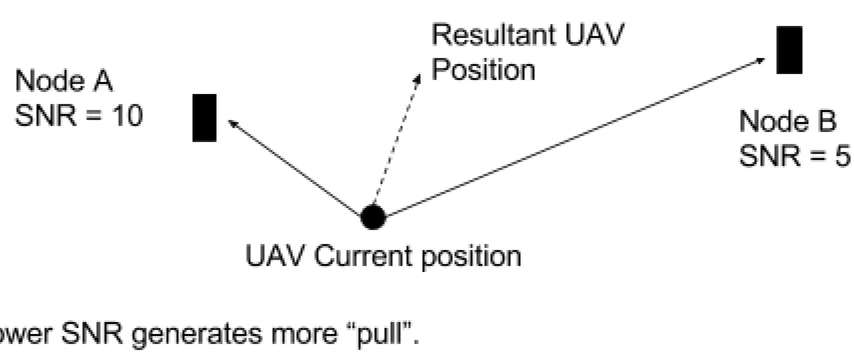
The current simulation is a basic representation of the ScanEagle and antenna characteristics, and there are several ways in which the system can be further developed.

- Forming a link quality metric that takes into account the parameters associated with antennas, such as throughput, will substantially increase the statistical significance and accuracy of the signal readings from the ScanEagle. This can be executed with Expected Transmission Count (ETX) created by Douglass Couto. Self proposed methods include the Average method where the parameter values are averaged to create a single value that can be compared, or the Threshold method where each parameter is individually assessed and grouped into categories indicating the quality of the link.

- Creating an efficient way to calculate the optimal position between the antennas should also be another area to focus on, as the current system searches every coordinate in the local grid for the maximum SNR. There is another program (autoOptimal) which autonomously searches for the optimal SNR position based on the SNR readings of the immediate 8 square meters around the vehicle. Perhaps this program can be run before the UAV with a quadcopter to mark an optimal position.
- Adding the 3rd dimension to the system could also facilitate more realistic simulations. The 2 dimensional circular field can be misleading as it does not account for the fresnel zone and vertical characteristics of signal fields.
- The system can also be adjusted to have optimal flight patterns for the UAV depending on the goal of the mission, such as time or energy preservation. In this situation, maximum SNR is optimal, as a result, flight orbit of the UAV could be flower-shaped to provide the least interference from the UAV wing while banking.



- The maximin algorithm could also be improved from its current sum method. Instead of adding the overlapping SNRs, a vector algorithm could be a better solution, where each node generates a stronger "pull" based on the lower strength of SNR it outputs. (Figure below)



- This system is robust in the way that it can be added on to. Future missions will include many elements, including more ground and mobile nodes. By utilizing emergent properties of the simple nodes in the current system, a more diverse and complex communications network can be created.

4. Acknowledgements and References

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