C-VIEW: Collaborative VIEW by Optimally Positioned Wireless Integrated Flying Robots

Maneesha V Ramesh
AMRITA Center for Wireless Networks and Applications
AMRITA Vishwa Vidyapeetham (AMRITA University)
Kerala, India
Email: maneesha@am.amrita.edu

Anjana Krishnan H
AMRITA Center for Wireless Networks and Applications
AMRITA Vishwa Vidyapeetham (AMRITA University)
Kerala, India
Email: p2wna09002@students.amrita.ac.in

Abishek T K
AMRITA Center for Wireless Networks and Applications
AMRITA Vishwa Vidyapeetham (AMRITA University)
Kerala, India
Email: abishektk@am.amrita.edu

***Abstract*—This paper describes a system that performs collaborative real-time sensing and monitoring of a disaster-hit area, using multiple Wireless Integrated Flying Robots (WiFR). These multiple WiFRs are designed to sense different environmental parameters; record images of the disaster hit area, and transmit these images to the command and control station (CCS). Each WiFR in the system has the capability to monitor unique regions, locate its position in real-time, and navigate to other regions according to real-time commands from the CCS. WiFRs are also integrated with collaborative sensing, processing, analyzing, and communication techniques. The efficient working of this multiple WiFR system requires the determination of the location of each of WiFR, the optimum number of WiFRs required for monitoring the entire disaster area, the paths with which minimum data packet loss and delay can be achieved, etc. Decision-making is dependent on various environmental propagation effects. During adverse environmental conditions, the WiFRs will use collaborative sensing as well as processing and analyzing techniques to determine the adaptable routes, thus avoiding the effects of wireless propagation and minimizing delay. Considering the capabilities of multiple WiFRs, this paper proposes an optimal positioning strategy of WiFRs that will effectively minimize the communication delay with respect to the dynamic propagation effects. An effective approach is also developed for determining the optimal density of WiFRs, to achieve guaranteed degrees of coverage. These results will provide important aspects necessary for effective disaster management.**

Keywords - Collaborative monitoring; Collaborative Sensing; Wireless ad-hoc network; Propagation effects; Disaster Management; Communication delay; Flying Robots

I. Introduction

In recent times, natural and man-made disasters are increasing at an exceptionally high rate in the world. Various disasters like earthquake, tsunami, landslides, volcanic eruptions, and cyclones are natural hazards that devastate the natural habitat and property very often [1]. Some measures need to be adopted in order to provide an early warning of the occurrence of such natural hazards and also to help in conducting emergency operations after its occurrence. Unmanned Aerial Vehicles (UAV) proves to be one of the most effective tools for real time monitoring of a disaster hit area and also aid in quick rehabilitation of the affected region.With the advent of wireless technology, an intelligent UAV system can be designed by incorporating various sensors and wireless routing and communication techniques.

The proposed system aims at performing collaborative real-time monitoring of a disaster hit area by using multiple Wireless Integrated Flying Robots (WiFR). C- VIEW helps in emergency rescue and rehabilitation operations by incorporating collaborative sensing, navigating, image processing, analyzing, adhoc routing and wireless communication modules. Each WiFR in the system has the capability to monitor a unique region, locate the WiFRs position, navigate to other regions according to real-time requirements, and adaptively route the data to the nearest ground command and control station (CCS). The data is collected in the form of images and the quality of the images captured need to be maintained. Also the data has to be transmitted to the nearest CCS at the earliest in order to conduct the necessary emergency operations.

The aerial positioning of the WIFR network and the dynamic propagation effects influence the quality of images, communication range and the delay incurred during the transmission of data to the nearest CCS. This paper studies the various effects of propagation on the C-VIEW system when it is positioned in the lower regions of the atmosphere, namely troposphere. It also identifies the most optimal range for the height of operation such that the image quality is high and the wireless propagation of data is less prone to adverse atmospheric effects.

The rest of the paper is structured as follows. Section II describes the various research works that helped us to propose the system. Section III discusses the architecture of the C-VIEW system. Section IV describes the various tropospheric effects on the monitoring system. Section V highlights the simulation results obtained and Section VI describes the conclusion and future work.

II. Related Works

Researchers from Hokkaido University, Japan describe the use of aerial robots for quick information gathering of a disaster area. The system uses a helicopter to collect the initial disaster information, the blimp and wire balloon system to survey the victims under collapsed houses and the captive balloon to monitor the suffered area continuously [3]. This system uses three different aerial vehicles to assemble data during three different phases of the scenario. Whereas the multiple WiFRs used in the proposed architecture are identical and consistently monitors the disastrous area in real time.

A.K Shukla et al discusses about the atmospheric effects that could occur during the fusion of data collection from different radars. This paper describes the impact of refractivity, ducting, scintillating atmosphere, diffraction and other factors during data fusion [4], whereas the proposed system discusses the influence of various tropospheric effects on the C-VIEW monitoring system.

Lkhagvatseren. T et al details the propagation of electromagnetic waves in an indoor environment. The paper makes a comparison between the most commonly used propagation models and explains a method for propagation and penetration measurement. It focuses on the propagation of RF signal in 1 - 8GHz range and conducts experiments in various laboratory set ups [5].

III. Architecture Of The Real Time Adhoc Networked C-VIEW System

The two main modules of the collaborative monitoring system are the Wireless Integrated Flying Robot (WiFR) and the Command and Control Station (CCS). The WiFR module incorporates four functioning modules - WiFR Navigation Module (WNM), Collaborative Sensing and Monitoring Module (CSMM), Adhoc Routing Module (ARM) and Wireless Transmission and Reception Module (WTRM) as shown in Figure 1.

The functioning modules of the Command and Control Station (CCS) include the Wireless Transmission - Reception Module (WTRM), Image Processing and Analyzing Module (IPAM) and Rescue and Rehabilitation Module (RRM). The complete architecture of the C-VIEW monitoring system is shown in Figure 2. The function of various modules in the proposed architecture is as follows:

A. WiFR Navigation Module(WNM)

Each of the WiFRs in the system is embedded with a GPS system to aid in localization and navigation of the WiFRs.

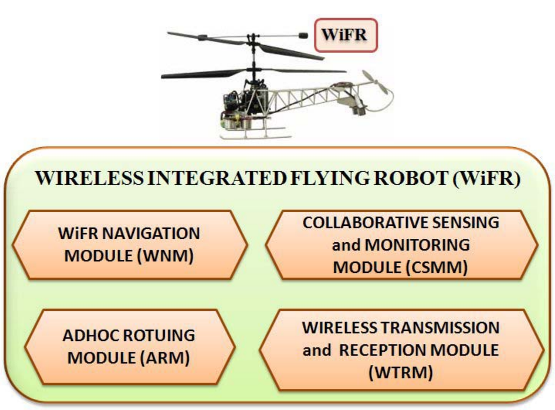

Fig. 1. WiFR Block Diagram

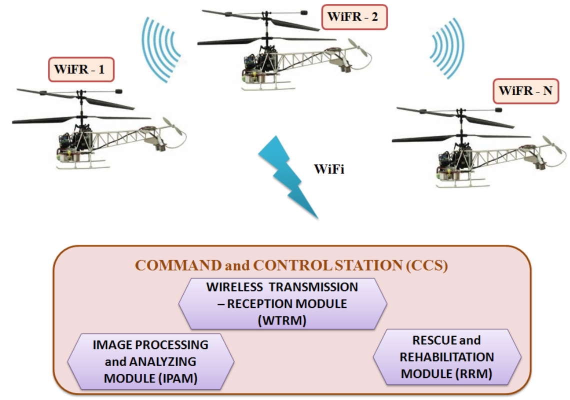

Fig. 2. Architecture of the Real Time Adhoc Networked C- VIEW System

The CCS specifies the coordinates for aerial positioning of the WiFRs via wireless communication. On reception of the coordinate information from the CCS, the WiFRs navigate for a short period and stabilize themselves in the required coordinates with the help of the GPS system. WiFRs also flies a short distance in order to monitor its assigned area of coverage. During the time of adverse environmental conditions, they navigate to a safer position according to the real time commands from the ground CCS.

B. Collaborative Sensing and Monitoring Module (CSMM)

Multiple WiFRs form an adhoc network to perform efficient monitoring of the disaster hit area in real time. Every WiFR in the network communicates with each other in an organized manner using wireless communication techniques. The current location coordinates computed using GPS and the measure of individual swath width assigned by the CCS is exchanged between the WiFRs. A high resolution camera embedded in every WiFR captures the images of the disastrous area and since each WiFR monitors unique regions of the devastated area, it avoids duplicity in the images captured and reduces the time complexity for image processing. The proposed system also permits the number of WiFRs to be dynamically incremented or decremented based on the severity of the hazardous situation. The system will adapt to the variation in the count of WiFRs according to the commands from the CCS. The CSMM also consists of pressure sensor, temperature sensor, water vapor pressure sensor and altimeter to collect the data necessary for studying the tropospheric effects on wireless propagation of data between the WiFRs and to the CCS.

C. Adhoc Routing Module (ARM)

Data transmission between the WiFRs and WiFR to the CCS is implemented using WiFi connectivity. The proposed system C-VIEW uses a hybrid hierarchical adhoc routing protocol namely Order One MANET Routing Protocol (OORP) for routing the data efficiently [11]. In OORP each node or WiFR elects a parent node that has connectivity to maximum number of nodes in the network. At the top level, one or more nodes are elected as the parents of the entire network. When a WiFR wants to transmit its data, it sends a request to the root of the tree and an optimal path is dynamically planned based on the Dijkstra's algorithm [11]. This routing mechanism has less communication delay, small memory requirements, and is capable of maintaining large number of nodes in the network. The WiFRs capture the real time images of the catastrophic area and transmits it to the CCS via the dynamically routed adhoc path.

D. Wireless Transmission and Reception Module (WTRM)

The central module of the C-VIEW system is the WTRM which is responsible for enabling wireless communication between the WiFRs and also between the WiFR and the ground CCS. The WiFRs transmit their current position coordinates and swath width information to other WiFRs in the network via the 2.4GHz WiFi connectivity. The real time images of the hazardous area captured by the WiFRs are adaptively routed through the adhoc network and transmitted to the CCS via wireless WiFi propagation mechanism. Also, the tropospheric effects on the WTRM of the system are studied to optimally position the WiFR network in the troposphere and minimize the transmission loss.

E. Image Processing and Analyzing Module (IPAM)

IPAM is a functioning module in the CCS where the images captured by the WiFRs are processed to identify the risk prone and risk free areas in the disaster hit area. A structured template matching algorithm proposed in [12] is used for processing and analyzing the images in the ground CCS. It is a three-layered structured template matching method which enables even recognition of very small objects with less computation load [12]. After processing the images captured, it is analyzed to detect the presence of human in the hazardous area and then initiate immediate service to aid them. Also the images are used to identify those regions that require immediate execution of rescue and relief operations.

F. Rescue and Rehabilitation Module (RRM)

The results from the IPAM indicate which zone in the disaster hit area requires instantaneous service of the RRM team. The RRM team is responsible for conducting emergency evacuation operations in the extremely devastated areas. The control team in RRM sends out warning messages to the public to stay away from the restricted areas. They also send information to doctors to provide initial first aid to injured victims and then provide them further medical assistance. They also initiate rehabilitation operations in the regions where the catastrophic scenario has started to subside. The RRM team also makes arrangements for funds, food and clothing for all victims of the disaster.

IV. Tropospheric Effects on the C-VIEW System

The three main factors that affect an efficient monitoring by the C-VIEW system are image quality, transmission delay and atmospheric effects on wireless propagation of data. The troposphere layer is the lowest layer of the atmosphere and extends to an altitude of 20kilometers from above the surface of the earth [7]. In the troposphere, the WiFR network can be positioned between 100meters to 300meters in order to suffice the requirements for efficient monitoring by the C-VIEW system. It is the most optimal operational altitude for the WiFR network because below 100meters, several obstructions from the earth's surface will be present and above 300meters formation of clouds begins which will adversely affect the wireless communication mechanism and image quality.

The factors that affect the WiFR network when placed in troposphere are as follows:

A. Tropospheric Refraction

Tropospheric refraction is a phenomenon that causes the bending and slowing of the radio waves by deviating from its straight line path and bending slightly towards the ground. It occurs due to the variation in refractive index. In the troposphere, the refractive index decreases with increase in height [6]. The refractive index n is given by,

$$n = 1 + N * 10^{-6} \qquad (1)$$

where N is the refractivity [4]. Refractivity is calculated using the following equation ,

$$N = 77.6 * \left(\frac{P}{T}\right) + 3.73 * 10^5 * \left(\frac{e}{T^2}\right) \qquad (2)$$

where P is the atmospheric pressure in hPa, T is the absolute temperature in Kelvin and e is the water vapour partial pressure in hPa [6]. Since the C-VIEW system is dependent on altitude, [6] the refractive index can be modified to incorporate the altitude factor h as,

$$M = N + \frac{h}{a} \qquad (3)$$

where h is the altitude in meters and a is the earth's radius in kilometers. Therefore, the path loss due to refraction based on refractivity is expressed as,

$$Ref_{loss} = 10 \log(M) = 10 \log(N + \frac{h}{a}) \qquad (4)$$

B. Tropospheric Scattering

Tropospheric scattering is due to the presence of turbulence, rain water, dust, fog, smoke etc., in the atmosphere. Transmission of radio waves experience turbulence several times, during its propagation through the troposphere. Each time the radio wave passes through the turbulence, the signal energy will be reduced due to scattering. Thus the received signal energy is equal to the sum of energy received from each of the turbulences [7]. This weakens the signal strength and can result in the loss or error in the transmitted data. Rain scattering is purely a microwave propagation mode and is best observed around 10 GHz transmission frequencies. In our research work we are neglecting scattering due to rain water, dust, fog, smoke etc. Therefore, [8] scattering loss is defined by the equation as,

$$Scat_{loss} = \exp\left[-8 * \left(\frac{\Pi \sigma_h \sin\theta_i}{\lambda}\right)^2\right] \qquad (5)$$

where σ_h is the standard deviation of the surface height about the mean surface height, θ_i is the angle of incidence and λ is the wavelength. θ_i can be determined using Snell's law and λ can by determined from the equation given below,

$$\lambda = \frac{c}{f} \tag{6}$$

where c is the speed of light in meters per second and f is the frequency in hertz.

C. Tropospheric Ducting

In normal atmospheric conditions, the temperature decreases with an increase in the altitude. But due to climatic variations, the temperature increases with an increase in altitude resulting in temperature inversion. Temperature inversion leads to a phenomenon called ducting. There are three types of ducting namely surface-based ducts, elevated ducts and evaporation ducts [9]. Ducting effects are more pronounced in very high frequencies and in regions close to the earth's surface. They also create a minor impact on lower frequencies. Tropospheric ducting occurs mainly when the refractivity N falls below-157 N/km. The tropospheric ducting loss [10] can be expressed as,

$$Duct_{loss} = 10\ \log\left(M + 0.13\left[z - z_d \ln\left(\frac{z+z_0}{z_0}\right)\right]\right) \tag{7}$$

where M is the modified refractivity, z is the altitude in meters, z_d is duct height in meters and z_0 is the duct strength.

D. Free Space Path Loss

Path Loss is defined as the measure of average attenuation experienced by the transmitted signal when it reaches the receiver after passing through a path of different wavelengths [5]. The path loss in free space propagation [6] is given by,

$$PL_{free-space} = 32.44 + 20\ \log d + 20\ \log f \tag{8}$$

where f is the operating frequency in MHz and d is the distance in kilometers.

E. Total Path Loss

The total path loss of the C -VIEW system can be computed as the sum of path loss incurred due to tropospheric refraction, tropospheric scattering and tropospheric ducting. Taking into account the free space path loss, the computed sum is subtracted from free space path loss to obtain the total path loss of the system. Therefore, the total path loss of the C-VIEW system during wireless transmission of data is given by,

$$PL_{total} = \begin{cases} PL_{free-space} - (Ref_{loss} + Scat_{loss} + Duct_{loss}) : \\ \qquad\qquad if\ N < -157N/km \\ PL_{free-space} - (Ref_{loss} + Scat_{loss}) : \\ \qquad\qquad otherwise \end{cases} \tag{9}$$

V. Simulation Results

Simulation results have been obtained for all the tropospheric effects influencing the C-VIEW system data transmission. In equation(3), both N and h varies. In our study, we need only 100m to 300m, hence h value varies from 100m to 300m. The value of N can be determined from equation(2). To calculate the value of N we require real time pressure, temperature and water vapor pressure values which can be received from the sensors attached to the WiFRs. For simulation purpose, the water vapor pressure value is assumed as 40hPa, pressure values and temperature values are obtained from [2].The Figure 3 obtained after computing the equation(4)show that the path loss due to refraction decreases with increase in altitude. Tropospheric scattering loss is computed using the equation(5). Scattering is frequency dependent and for our simulation frequency is taken as 2.4GHz.The results obtained in Figure 4 shows that scattering loss in the troposphere decreases with increase in frequency. Simulation results for tropospheric ducting has been implemented based on equation(7).Ducting occurs when the modified refractivity value falls below -157 N/km. The duct height has been assumed to be equal to 50m for simulation purposes. The duct strength value has been assumed to be equal to 1.5 x 10^{-4} meters. The results in Figure 5 show that the path loss decreases in longer distance due to ducting. Free space path loss has been simulated based on equation(8) as shown in Figure 6. The frequency assumed for our application is 2.4GHz and altitude range considered is 100m-300m. Results indicate that the free space path loss increases with increase in altitude. The total path loss incurred by our application is

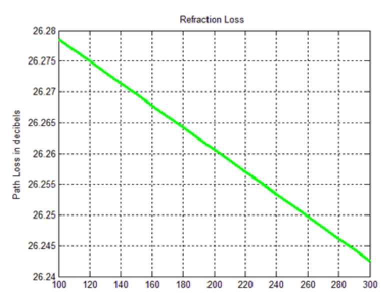

Fig. 3. Tropospheric Refraction Loss

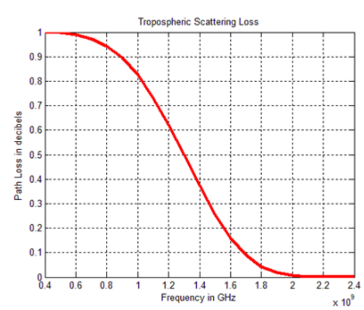

Fig. 4. Tropospheric Scattering Loss

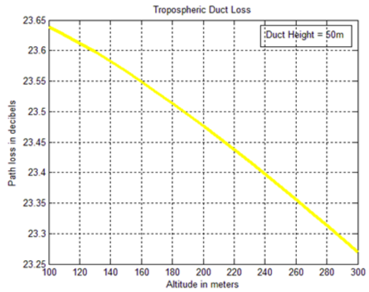

Fig. 5. Tropospheric Ducting Loss

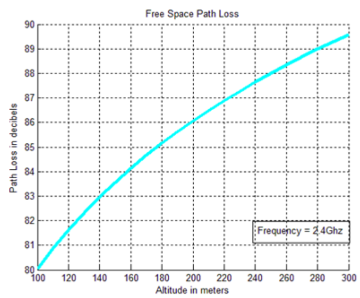

Fig. 6. Free Space Path Loss

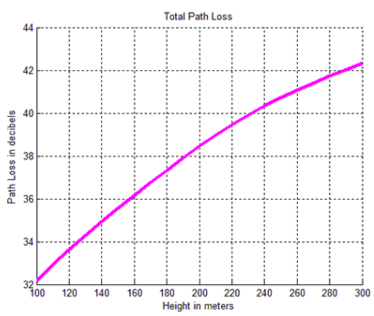

Fig. 7. Total Path Loss

computed using equation(9) and the simulated graph is shown in Figure 7. Tropospheric Duct loss is considered only when the refractivity goes below -157 N/km. From the simulated graph we see that for a height of 100m-300m, we get total path loss in the range of 32dB - 43dB.

VI. Conclusion and Future Work

The proposed system has been designed to perform real time collaborative monitoring of a disaster hit area using multiple Wireless integrated Flying Robots (WiFRs). The C-VIEW system incorporates several functioning modules for navigation, collaborative sensing and analyzing, adaptive routing, image processing and wireless transmission of data collected. The efficiency of the monitoring system depends on atmospheric effects, image quality and transmission delay. This research paper focuses on these three factors to improve the efficiency of the system and thereby aims to reduce the atmospheric effects and transmission delay of the system and increase the quality of the images captured by the WiFRs. The paper makes a study of various tropospheric effects that can influence our system and computes the total path loss incurred during wireless propagation using 2.4GHz frequency band. The simulation results obtained are effectively used to determine the optimal aerial position of the WiFRs and also to compute the optimal density of WiFRs required for monitoring the disastrous area in its entirety. In future, the current research will be extended to analyze k-connectivity and coverage by the WiFRs in the monitoring system and to also compute the most feasible frequency range for transmission of data. Also the proposed system will be implemented, tested and validated in AMRITA University for in depth analysis of tropospheric propagation effects on wireless communication.

Acknowledgment

The authors would like to express gratitude for the immeasurable motivation and guidance provided by Sri. (Dr.) Mata Amritanandamayi Devi (AMMA), Chancellor of Amrita University. We would like to express our gratitude to AMRITA University for providing all the support and facilities to do the research work. We also take this opportunity to thank Mr. K.A Unnikrishna Menon and Mr. Josh D Freeman for their valuable contribution to this research work.

References

[1] Marline Claessens and Nicolas Lewyckyj, *PEGASUS:A UAV Project For Disaster Management*, Proceedings of the 2nd International ISCRAM Conference,April 2005.
[2] Masahiko, *Weather*,www.csgnetwork.com.
[3] Onosato, Fumiaki Takemura, Kenzo Nonami,Kuniaki Kawabata, Kenjiro Miura and Hiroaki Nakanishi, *Aerial Robots for Quick Information Gathering in USAR*, SICE-ICASE International Joint Conference 2006 in Bexco, Busan, Korea.
[4] A.K Shukla D J Fraser, ALockton, AHYChan, JENField, S LShemar, *The Impact of Tropospheric Propagation on Data Fusion from Multiple Radars*, 7th International Conference on Information Fusion (FUSION), IEEE 2005.
[5] Lkhagvatseren.T and Hruska.F , *Path loss aspects of a wireless communication system for sensors*, International Journal of Computers and Communications, Issue 1, Volume 5, 2011.
[6] Herve Sizun, *Radio Wave Propagation for Telecommunication Applications*,Springer, 2005.
[7] Electrical Engineering Training Series, *Tropospheric Propagation*,www.tpub.com.
[8] Theodore S Rappaport, *Wireless Communicationt*,Principles and Practice, Second Edition, Prentice Hall of India, 2008.
[9] Herbert V Hitney, Juergen H Richter, Richard A Pappert, Kenneth D Anderson, and Gerald B Baumgartner, *Tropospheric Radio Propagation Assessment*,Proceedings of the IEEE, VOL. 73,NO,2, February 1985.
[10] I.Sirkova and M.Mikhalev, *Parabolic Wave Equation Method Applied to the Tropospheric Ducting Propagation Problem:A Survey*,Electromagnetics, 26:155-173, 2006.
[11] Fenglien Lee, *Routing in Mobile Adhoc Networks*,Mobile Adhoc Networks: Protocol Design, Edited by Xin Wang,www.intechopen.com, ISBN-978-953- 307-402-3.
[12] Toshio Modegi, Tomoaki Inazawa, Tsugio Chiba and Chiaki Kobayashi, *Small Object Recognition Techniques Based on Structured Template Matching for High-Resolution Satellite Images*,www.intechopen.com,ISBN: 978-953-307-222-7,Publisher: InTech.