Study of Ultraviolet Mobile Ad Hoc Network

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***Abstract*—Mobile ad hoc network (MANET) as an up-to-date wireless network has some unique features such as topology alters constantly, infrastructure-free, any node within the network is communication destination as well as router, etc. These characteristics of MANET give rise to its great flexibility and cost efficiency. Traditional MANET operates in the radio frequency (RF) spectrum, where the available bandwidth is facing the challenge of rapidly increasing demands. Ultraviolet (UV) provides a feasible complement to RF wireless MANET because some of its advantages: miniaturized device, low-cost implementation, non-line-of-sight (NLOS) communication, high security, low background noise and potential high speed data rate. In this paper, we investigate several aspects of the performance of the combined UV MANET by simulation. Various issues related to the performance of UV MANET such as Throughput, bit error rate (BER) and signal/noise ratio (SNR) were collected and analyzed. The analysis will be of great assistance in the design and implementation of such UV MANET.**

Keywords-MANET; UV; Propagation model; simulation

I. INTRODUCTION

Unlike wireless network with predefined infrastructures such as mobile cellular networks, mobile ad hoc networks (MANETs) are infrastructure-free networks with no administrative node. Any nodes within the networks may come and go, turn on and off unpredictably, move continuously leading to a volatile network topology with communications between nodes that are also modified time to time. These features of MANET give rise to its great flexibility and cost efficiency. Previous study on MANET mainly focused on radio frequency (RF) based networks, rarely discussed that with a wireless optical link [6]. However, the available bandwidth now is facing the problem of rapidly increasing demands. Free space optical (FSO) communication provides an attractive complement to RF wireless MANET. There are a host of advantages that make an UV MANET worth to take into consideration. These advantages include huge unlicensed bandwidth, low-power and miniaturized transceiver, higher power densities, high resistance to jamming, and potential increase of data rate [2].

Infrared once seemed to be a suitable choice because of its line-of-sight (LOS) feature [3]. Nevertheless, an infrared link is susceptible to obstacle because of its rectilinear transmission. In some special scenarios, for example, battle fields, some region with complicated terrain, a linear and direct link is unavailable. All of these together with solar background noise significantly limit the large area deployment of infrared communication.

Ultraviolet (UV) communication as a state-of-the-art realm of research in recent years may tackle with these limitations. First, according to [2], UV is usually defined as electromagnetic wavelengths between 4nm and 400nm. Over the whole spectrum, UV-C (280~200nm) is solar blind. When traverse earth's atmosphere, the solar radiation will lose almost all the energy in the UV-C spectrum. So operating in this region, the background noise is low. Second, due to its short wavelength, UV waves' scattering model is omni-directional, which makes the non-line-of-sight (NLOS) communication possible. Third, because of strong attenuation by atmosphere, signal beyond the extinction range can hardly be intercepted, which also enhancing the security. Additionally, huge bandwidth could deliver high rate data [5]. All these appealing characteristics of UV have made UV-based system to be an ideal model to deploy UV MANETs --- low-cost implementation, NLOS, high security, low noise and potential high speed data rate. Fig. 1 shows a typical model of NLOS UV communication system.

Our purpose is to investigate the performance of our combined UV MANETs. Such networks would provide improved performance for wireless communications where infrastructure is unavailable, for example, battlefield applications and disaster recovery situations. It also suits the needs of secure short-range communications, with no requirement to see each communication destinations directly. To fully evaluate the performance of such hybrid system, we need to create modules to collect some key related statistics of UV MANET such as BER, SNR which based on different MANET routings.

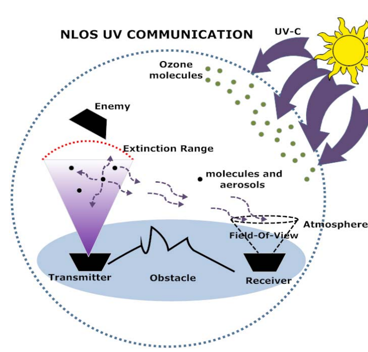

Figure 1. Example of NLOS UV communication

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The rest of the paper is organized as follows: Section Ⅱ investigates several related issues including the propagation model of UV communication and the routing protocol in MANET that will be implemented in our model; Section Ⅲ describes modeling such a network using OPNET Modeler, a simulation software environment; Section Ⅳ analyzes simulation results; and Section Ⅴ lists conclusions and future works.

II. RELATED WORK

A. Propagation Model

Common UV communication is a process as follows: UV photons as the carrier to carry the signals, these photons are transmitted by transmitter; the UV photons could not transmit directly from transmitter to receiver. They need some atmospheric molecules and aerosols (as relays) to approach to the receiver. The phenomenon is called Rayleigh scattering and Mie scattering, respectively [10]. Except very small quantities of photons absorbed by ozone molecules, large amount numbers of these UV photons would arrive to receiver via one or several times scattering (as shown in Fig. 1). If the distance between particles is much longer than its own radius then each particle is independent of any other particles [7]. So we assume that any single UV photon that transmits from transmitter to receiver scatters at most one time. This is very important for simplifying the propagation model. For simulation consideration, we need some expressions and functions which could efficiently evaluate some system and geometry parameters. Unfortunately, the total path loss of UV transmission can not be calculated by the use of radiation law directly. Step-by-step analysis in [3] [8] [9] provide us an approximated expression to evaluate the final received optical power by the receiver, as shown in expression (1).

$$E_r \approx E_t k_s P(\mu) A_r V \sin^4\theta_s \exp[(-k_e r)(\sin\theta_1+\sin\theta_2)/\sin\theta_s]/2\pi r^4 \sin^2\theta_1 \sin^2\theta_2(1-\cos(\phi_1/2)) \quad (1)$$

Where E_t is the total transmitted energy, E_r is the total received energy. $P(\mu)$ is the scattering phase function where $\mu=\cos\theta_s$, V is the transmitter (Tx) and receiver (Rx) common volume, r is the distance between Tx and Rx, θ_1 and θ_2 as the Tx and Rx apex angles between each axis and the horizontal axis, and ϕ_1 as the Tx full beam angle, k_e is the extinction coefficient of the atmosphere obtained from the scattering and absorption coefficients by $k_e=k_s+k_a$. Also, $\theta_s=\theta_1+\theta_2$ is the angle between the forward direction of incident waves and the observation direction, A_r is the area of the receiving aperture, as shown in Fig. 2. The expression (1) will be applied in the simulation part after a while.

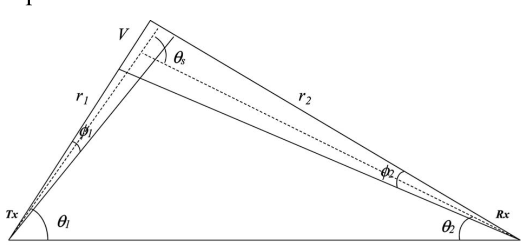

Figure 2. A NLOS UV communication link

B. Routing Protocol in MANET

For the consideration of evaluating the performance of UV MANET, one of the most important issues is to design or choose a suitable routing algorithm. This is because routing protocol is the underlying condition for a MANET to work efficiently.

Our primary consideration is to design a new routing algorithm to meet uniquely the UV MANET requirement. However, we choose Dynamic Source Routing (DSR), a classic routing protocol to fulfill our task for time consideration.

DSR protocol is defined as a kind of reactive protocol. It has two major components: Routing Discovery Mechanism and Routing Maintenance Mechanism. Fig 3 illuminates the operation of DSR protocol. Routing Discovery Mechanism works like this: If node S wants to communicate with node D, first it need to broadcast a Route Request (RREQ) packet in the network. This RREQ contains some useful information such as the source address of this RREQ, the destination address, a sequence number (set by the initiator and used to identify the request), and a route record. A node would propagate the RREQ if it is not the destination of the RREQ and if it is the first time it receives this packet. If the node already has a valid route to the destination in its route cache, it generates a Route Reply (RREP) packet back to node S immediately. This RREP contains a complete valid route from node S to node D. It also includes some information like destination address (source address of the RREQ), relay address that represents the next hop address of the RREP and also the sequence number same as the RREQ. But it is also possible that no node along the way before node D already has a valid route from node S to node D in its route cache. In this case, node D sends a RREP packet directly which contains the common information mentioned above and inserts this valid route to its route cache at the same time. Node D then will discard all RREQ corresponding to the same route discovery process after sending the RREP. The Route Maintenance Mechanism ensures that the paths stored in the route cache are valid. If the data link layer of a node detects a transmission error, that means it detects that the data packet can not be received by next hop (use either wait-stop mechanism or a default waiting time), then the node creates a Route Error packet and transmits it to the original sender of the data packet. When a node receives a Route Error packet, it removes the link that related to this error link, truncates the route from the hop before the broken link. Then this node will originate a new route discovery process to find a new valid path to the destination. DSR is suitable not only to common MANET, but also applicable to our UV MANET model because UV communication has a short range, signals often can not transmit for long distance, so multi-hops routing and a route cache is desirable. More details about DSR are in [10].

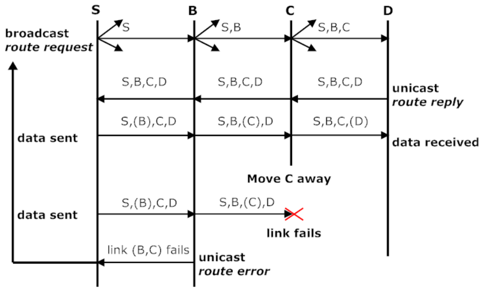

Figure 3. Operation of DSR protocol

III. SIMULATION MODELS AND PARAMETERS

After the analysis of propagation model of UV MANET and the choice of routing protocol, we will step into the simulation stage. OPNET Modeler [11] was chosen to fulfill the simulation task because it is easy to deploy a MANET with predefined nodes and it is very comfortable to use its own graphical user interface.

However, we encounter some difficulties. The predefined MANET node models in OPNET are all RF models. So we need to modify these models to meet our own purpose. The modification includes antenna patterns, transmission range, central frequency and propagation model.

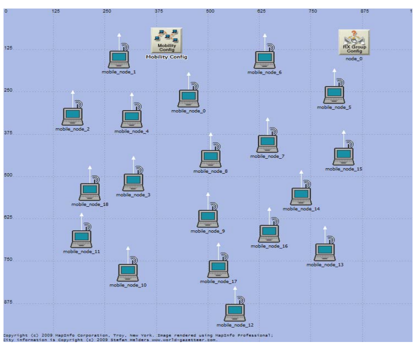

Figure 4. Network in OPNET

In OPNET, MANET models do not have any antennas, but just a wlan_tx and a wlan_rx to accomplish the transmission and receive function. But we need to design an antenna pattern to accommodate the reality and also keep accordance with our propagation model discussed before. Fig. 5 shows the antenna pattern used in our model, for a given angles of aperture, it has a receiving gain provided by (1) and no gain in any other directions.

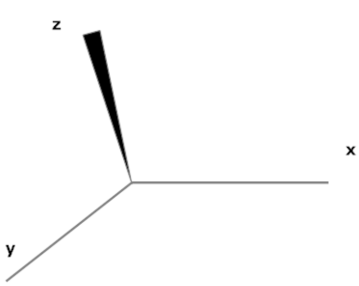

Figure 5. Antenna Pattern

For propagation model, we substitute the parameters in expression (1) with real values to establish a real path loss calculation. [8] Provides some details about the values used in function (1). We apply this propagation model to OPNET for our own purpose to evaluate the performance of our UV MANET. Our most concerned factors are: the total transmitting data and received data, end-to-end delay, bit error rate of given link and signal/noise ratio of such link.

We assume that there are mainly three types of traffic loads in this network – data, voice and video. Different types of traffic loads have different requirement of BER and delay. For Ftp 10^{-9} and for voice application 10^{-6} and video transportation 10^{-3}, respectively. For BER and SNR, we choose a specified link (end-to-end) to evaluate their performance. Other parameters in this model are as follows:

- Scenario Area: 1000m X 1000m
- Distance Threshold: 200m
- Data Rate: 2Mbps
- Mobility: Random Mobility
- Terrain: Indianapolis
- Duration: 1 hour
- Modulation: bpsk
- Packet Size: 256bits/packet

IV. SIMULATION RESULTS

The following results were obtained by running the simulation in OPNET:

Traffic Sent vs. Traffic Received:

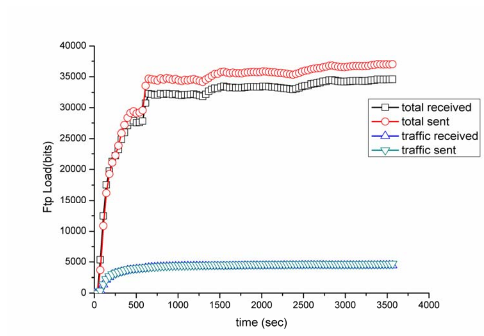

Figure 6. Traffic Receive and Sent of Ftp

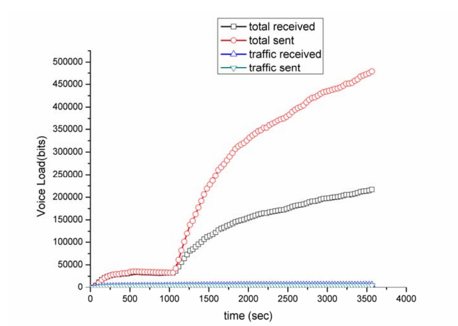

Figure 7. Traffic Receive and Sent of Voice

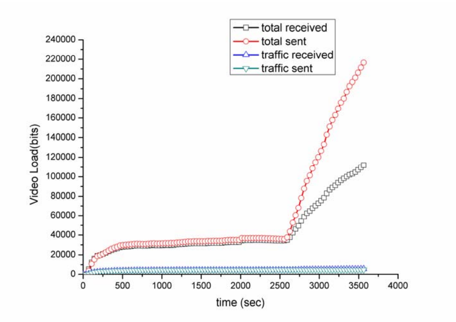

Figure 8. Traffic Receive and Sent of Video

Fig. 6 shows that when the application in the network is ftp, the total traffic sent and traffic received loads are similar, thus proving that most packets can successfully reached the destinations. From the graph, we can also obtain that the data rate is about 4KB/s. Moreover, about less than 15% loads are ftp loads, which means large amount of traffic loads are the routing traffics. Fig. 7 represents the voice load, when time beyond 1200 seconds of the simulation; the total received data are less suddenly than the total sent data, that means there are many packets that were not able to reach to its destinations. At the same time, there are more routing traffic loads than voice loads and voice loads are about 4000-6000bps. Fig. 8 indicates that when application in the networks is video, the curves in the graph is similar to that of in Fig. 7, but the time total traffic loads rise is later, the data rate is also similar to that of in Fig. 7. this means that routing traffic loads increase considerably after 2500 seconds.

Bit Error Rate:

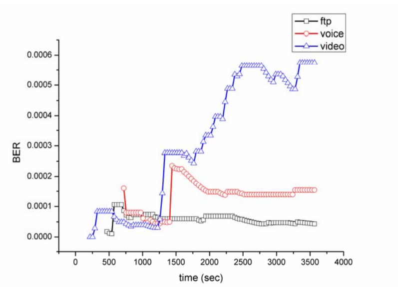

Figure 9. Bit Error Rate

Fig. 9 represents the BER for different traffic types. From the graph, we can obtain that for Ftp and Voice, the BER exceed the requirement, say 10^{-9} and 10^{-6}, respectively. But for video application, BER does not exceed the range 10^{-3}.

Signal/Noise ratio

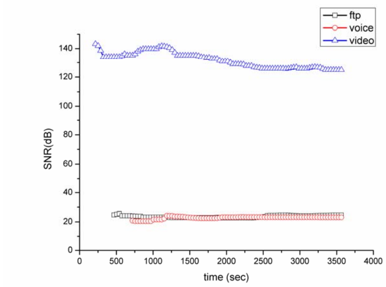

Figure 10. Signal/Noise ratio

Fig. 10 indicates the signal/noise ratio for the three traffic loads. From the graph, we can see that for voice and video, they had a good performance on SNR, proving that UV communication has a high Signal/Noise ratio and is suitable for short range communication.

V. CONCLUSIONS

This paper investigated the possibility of combination a UV communications module to an RF MANET in order to provide NLOS communication.

A preliminary study of propagation model and routing protocol provide us some details in UV MANET model.

Simulation models were developed in OPNET Modeler to study the performance of the UV MANET module. The simulation results show that the proposed UV MANET is feasible. Some system factors were also collected which are useful when design such network.

Future work includes the implementation of UV MANET to investigate its real performance.

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