Performance Evaluation of Hierarchical Routing Protocol with Multiple Transceivers and Cluster Based Routing Protocol in FSO MANET

Kavitha Balamurugan
Department of Electronics and Communication Engineering
KCG College of Technology, Anna University
Chennai, India
Email Id: kavitha@kcgcollege.com

K. Chitra
School of Electronics Engineering
VIT University
Chennai, India

A. Jawahar
Faculty of Electronics and Communication Engineering
SSN College of Engineering
Chennai, India

***Abstract*— In Free Space Optical Mobile Ad Hoc Networks, there are only few literature works on routing methods which lack the consideration of alignment. Hence, we propose Hierarchical Routing Protocol with Multiple Transceivers. When the source wants to transmit the data packet to destination this routing technique can be utilized for route establishment. In this method, clustering is done and then using network source connector, cluster head selection is done. After that source transmits packet based on the proposed data propagation model with multiple transceivers which helps to increase the transmission range and provides clear line of sight for routing in FSO. The advantage of this protocol can be seen from simulation results that Delay is 26% less, , Drop is 25% less and Throughput is 45% higher in the developed Hierarchical Routing Protocol with Optical Sphere (HROS) protocol than the existing Hierarchical Cluster Based Routing (HCBR) protocol.**

Keywords— Free Space Optics, Multiple Transceivers, Mobile Adhoc Networks, Clusters, Routing

I. INTRODUCTION

Free-space optical communication (FSO) is a technology that uses light which propagates in free space to send data wirelessly for communications. "Free space" means air. The technology is useful where the physical channel is not possible due to high costs.

FSO is a technology which is used mainly for high bandwidth and in wireless communication links. In FSO, an optical transceiver is placed on each side of a transmission path to establish a network link[1].The transmitter is an infrared (IR) laser or LED that emits a modulated IR signal. Link availability can be maintained under utmost weather conditions (except heavy fog, heavy rain has little effect).

FSO provides many benefits as compared to RF [2]:

- FSO does not require licensing and regulation so it is simple , faster and cost of deployment also is less.
- FSO transceivers can transmit and receive through windows, and also it is possible to mount FSO systems inside buildings thus reducing roof space requirements and simplifying wiring and cabling, thus permitting FSO equipment to operate in a favorable environment.
- The only essential requirement for FSO is line of sight between the two ends of the network link.
- FSO networks can close the last-mile gap and allow new customers access to high-speed MANs.
- On comparison with radio frequency transceivers, FSO transceivers are adjustable to dense integration, power consumption is less, modulation can be done at higher speeds and offer highly directional beams for spatial reuse/security.

A FSO transmitter-receiver is a pair of optical sources (e.g., Light Emitting Diode (LED)) and optical receiver (e.g., PIN Photo-Detector (PD)). Optical transceivers are cheap, small, weight is less,flexibility to dense integration (1000 + transceivers possible in 1 sq. ft), long life/ reliable (10 years lifetime), consume low power (100mW for 10–100 Mbps), can be modulated at high speeds (1 GHz for LEDs/VCSELs and higher for lasers), offer directional beams for spatial reuse and security, and operate in unlicensed spectrum compliant to wavelength-division multiplexing (infrared/visible).[2] As an offset to these advantages, FSO requires clear line-of-sight (LOS) and alignment between transcievers. FSO communication also suffers from beam spread with distance (tradeoff between per-channel bit-rate and power) and unreliability during bad weather especially when size of particles in the medium are close to the used wavelength (aerosols and fog).

The capacity gap between fiber links and mobile ad-hoc links is bridged by the high bandwidth spectrum of Free-Space-Optical (FSO) communication. Capacity problem is solved in FSO but LOS requirement problem persists [3].

Design and topology routing are the two important issues to be considered to improve the network performance of FSO by network design. Some of the existing routing algorithms [4-7] for FSO network are Delay-constrained minimum hop algorithm [4], All hops shortest paths algorithms [5] to determine the shortest feasible path with limitation on hop count. A minimum hop count with load balancing routing algorithm[6] that can manage traffic based on hop count of paths.

The routing protocols that use the reverse path technique[8] are Destination Sequenced Distance-Vector Routing Protocol (DSDV) and Ad Hoc On-Demand Distance-Vector Routing Protocol (AODV). These protocols do not consider the unidirectional links [8] so they cannot be directly applied to FSO MANET[9-15]. Further, local directionality [16] usage to route the packets in the network becomes an important issue." In order to overcome these directionality problems, spherical data path model with hierarchical routing protocol is developed for FSO.

Hierarchical routing protocol is a protocol in which clusters are formed based on neighborhood discovery algorithm[17,18]. Cluster and network source connector will build a routing table using the information collected from cluster head and network source connector discovery algorithm. The source uses FSO/RF MANET[9-15] routing protocols to send data to the destination node. End-to-end throughput and low delay are provided by the direct connection of network source connectors and routing algorithms. For clear alignment between transcievers hierarchical routing protocol with data propagation model[19] provides a spherical structure for data propagation in order to cover a large transmission area [20]. It also considers several factors[3] such as intensity of beam, divergence angle, geometric attenuation factor, and atmospheric attenuation factor to provide a clear LOS for communication.

The paper is organized as follows: Data Propagation Model is described in Sec. 2. It explains Multi Element Hierarchical Routing protocol. Simulation results are presented in Sec. 3. Conclusion with a brief summary is given in Sec. 4.

II. PROPAGATION MODEL USING MULTIPLE TRANSCIEVERS

This section explains the various metrics used in the protocol in order to provide a good routing path between source and destination. Fig. 1 shows the data propagation model.

Intensity of beam: At a distance L, the received power along the beam is denoted as B. According to Lambertian law, at any arbitrary angle γ from vertical axis and at a distance L, the distance is given by Eq. (1)

$$B_{\gamma,\mathrm{L}} = B_{\mathrm{L}} \cos(\gamma) \qquad (1)$$

The intensity of the beam [3] for any FSO transmitter can be improved by introducing a factor u. Hence, the intensity is given by Eq. (2)

$$B_{\gamma,\mathrm{L}} = B_{\mathrm{L}} \cos^{\mathrm{u}}(\gamma) \qquad (2)$$

Divergence Angle φ : If Beam radius is w_L then equation $\frac{B_{\gamma,\mathrm{L}}}{B_{\mathrm{L}}} = \frac{1}{e^2}$ holds. The divergence angle [3] can be calculated using Eq. (3)

$$\phi = \tan^{-1}\left(\frac{w_L}{L}\right) \qquad (3)$$

Geometric Attenuation Factor (A_F): Geometric attenuation factor[3] is defined as a function of transmitting node radius α, radius of the receiver μ cm, divergence angle of the transmitting node ϕ and distance between the transmitting node and receiver D.

FSO propagation can be affected by geometric attenuation and atmospheric attenuation factor. Hence, the source power S_P should be greater than power loss. Equation (4) shows the attenuation factor.

$$A_F = 10\log\left(\frac{\mu}{\alpha + 200D\phi}\right)^2 \qquad (4)$$

Atmospheric Attenuation Factor (A_P): Atmospheric attenuation factor is a factor that consists of absorption and dispersion of laser light photons through different aerosols and gaseous molecules in the atmosphere. According to Bragg's Law, the power loss happens due to the atmospheric propagation can be given by using Eq. (5)

$$A_P = 10\log\left(e^{-\beta D}\right) \qquad (5)$$

Where β represents the attenuation coefficient that contains the atmospheric absorption and dispersion. The wavelength used for FSO communication is more efficient than other losses. By using Mie scattering formula, the attenuation coefficient can be calculated as in Eq. (6)

$$\beta = \frac{3.91}{U}\left(\frac{\eta}{550}\right)^{-p} \quad (6)$$

Here, U represents the atmospheric visibility in kilometers, and p represents the size distribution of the scattering particle whose values depend on the visibility. The value of p is given by p = {1.6 U>> 50 km, 1.3 6km $\leq$ U $\leq$ 50 km, 0.583U$^{1/3}$ U< 6km}

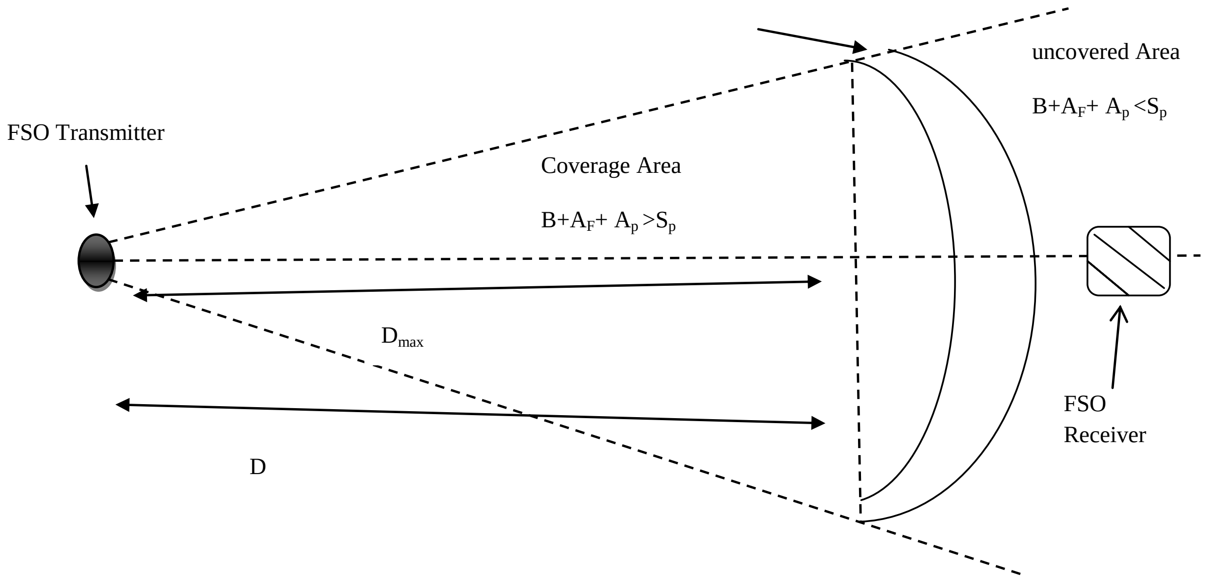

Fig.1. Data propagation model

II. Multi element hierarchical routing protocol

The different sections of multi element hierarchical routing protocol are described in the following section: Clustering Process, Network Source Connector Discovery Process and Multi Element Routing Protocol.

A. Clustering process

The clustering process mainly depends on the neighbor discovery algorithm (NDA)[17,18] in which each node maintains neighbor table[8] that consist of ID of the neighboring nodes and link status. In the clustering process,

N_i represents the node employed in the network. (Where i= 1, 2, 3……n)

N_{nbh} denotes the neighbor nodes.

C_i represents the clusters

CH_i represents cluster head

Let n (C_i) represents number of nodes in the cluster

SC_i denotes network source connector that connects hybrid networks and has some virtual link with all cluster members through CHs

Let Th denotes the threshold of node that can join in the network

The different steps involved for clustering process can be explained as below:

Step 1: First each SC_i node maintains neighbor tables that consist of information about neighboring nodes. Table 1 shows the information contained in Neighbor table.

Table 1. Information contained in Neighbor table

Neighbor Table	
Neighbor Node, N_{nbh}	Node link status

Step 2: After that each network source connector SC_i broadcasts HELLO message to its N_{nbh} which is present in neighbor table using NDA.

Table 2. HELLO message

Sender Node ID	Node Status	Neighboring Table	
		N_{nbh} ID	Status

The HELLO message as shown in Table 2 consist of sender nodes ID, status of sender node (for eg. about energy) and about status of the neighboring node.

Step 3: Once N_{nbh} receives HELLO message, it verifies whether the message contains its ID or not.

If HELLO message contains N_{nbh}'s ID

then N_{nbh} join SCi to form cluster

Step 4: The process in step 3 is repeated until predefined threshold of nodes to join the cluster is reached.

If n (C_i) < Th, then

Goto step 3

End if

Step 5: In this step N_{nbh} decides which node to join, if it receive more than one HELLO message.

If N_{nbh} receives more than one HELLO message, then

N_{nbh} joins SC_i with maximum energy.

End if

Step 6: From each cluster, the node which is closer to SC_i can be selected as CH (CH_i)

Fig. 2 shows that network source connector SC9 broadcasts HELLO message to all its neighbor nodes Nnb1, Nnb3, Nnb4, Nnb5, N nb7. Similarly NC6 and NC19.

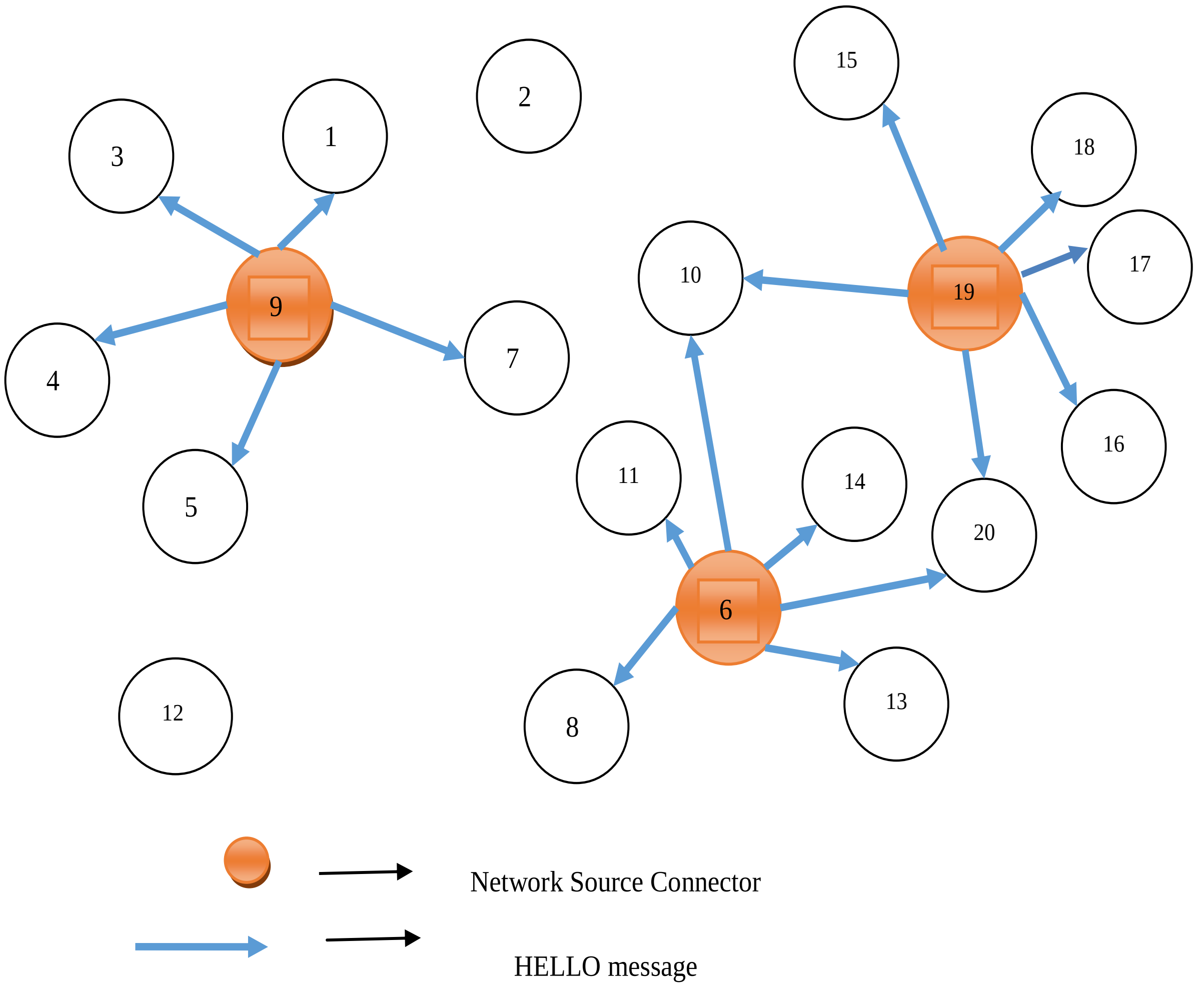

Fig . 2. HELLO message Transmission

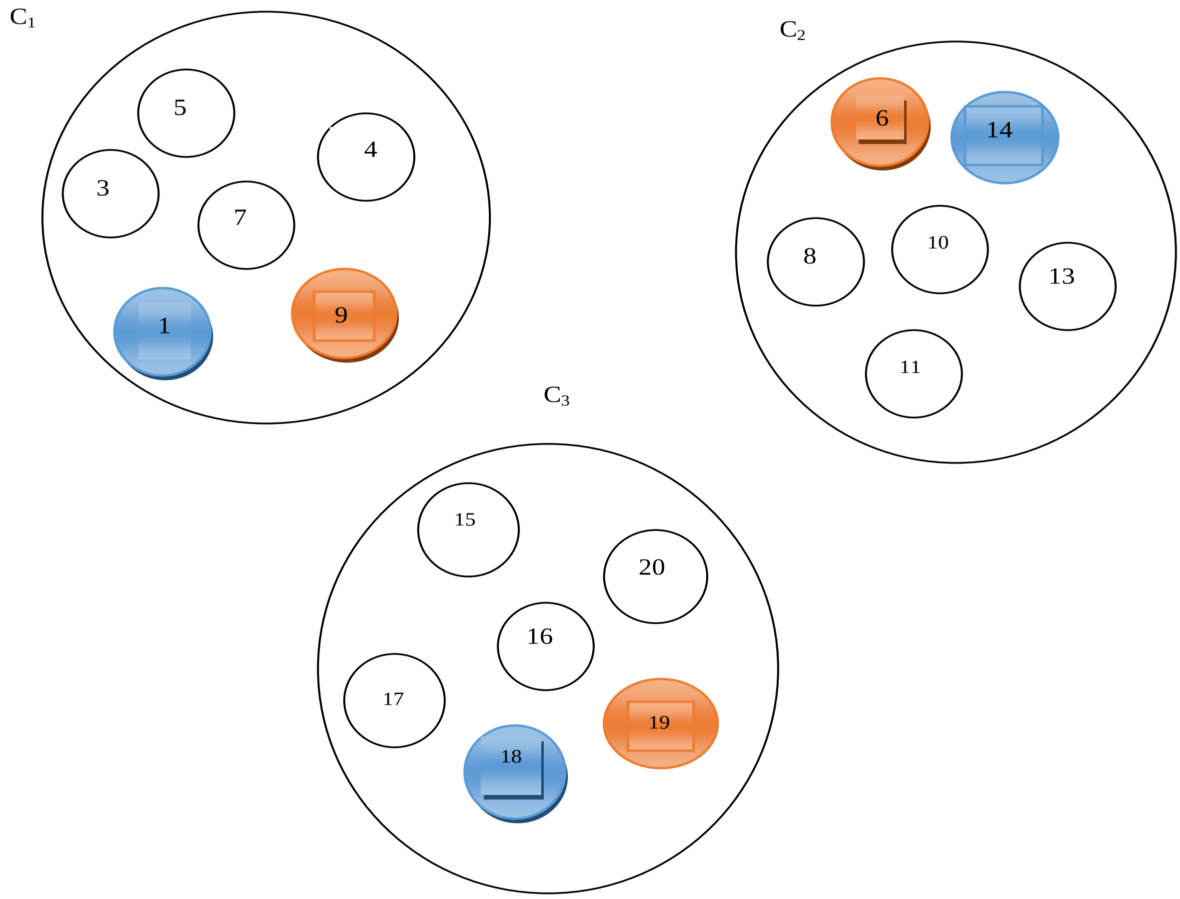

Fig. 3. Election of Cluster Head

In Fig. 3 the clustering process is shown. After clustering, node which is closer to node connector is elected as CH. For example in cluster C1, N1 is considered as CH because it is closer to SC9. Similarly N14 and N18 are elected as CH in C2 and C3 respectively.

B. Network source connector discovery process

Once clustering is done, all the information about the cluster member is maintained by the network source connector[17,18] in the routing table. This process is explained in the following section:

Here consider SC_{ID} as the identity of SC.
SQ_{ID} denotes sequence number of SC, and CM_i represents cluster members
CH_i represents cluster heads.
Assume that there are n clusters- {C1, C2, C3… Cn}. Each SC consists of routing table which contains information about all the cluster members and respective cluster heads.
The routing table is constructed based on network source connector discovery process which is described as below:
Step 1: Each SC_i sends network source connector discovery (NCD) message to all other SC_i in the network through CH_i
Step 2: Once NCD message is received, SC_i builds its routing table based on information contained in NCD as shown in Table 3.

Table 3. Format of NCD message

SC_{ID}	SQ_{ID}	CM_i	CH_i

Step 3: Repeat step 1 and step 2 until NC_i receives NCD message from all CH i.e. from CH_n
Step 4: Once NCD message is received each SC_i create table with information received from NCD message. Fig. 4 shows the broadcasting of the NCD message.

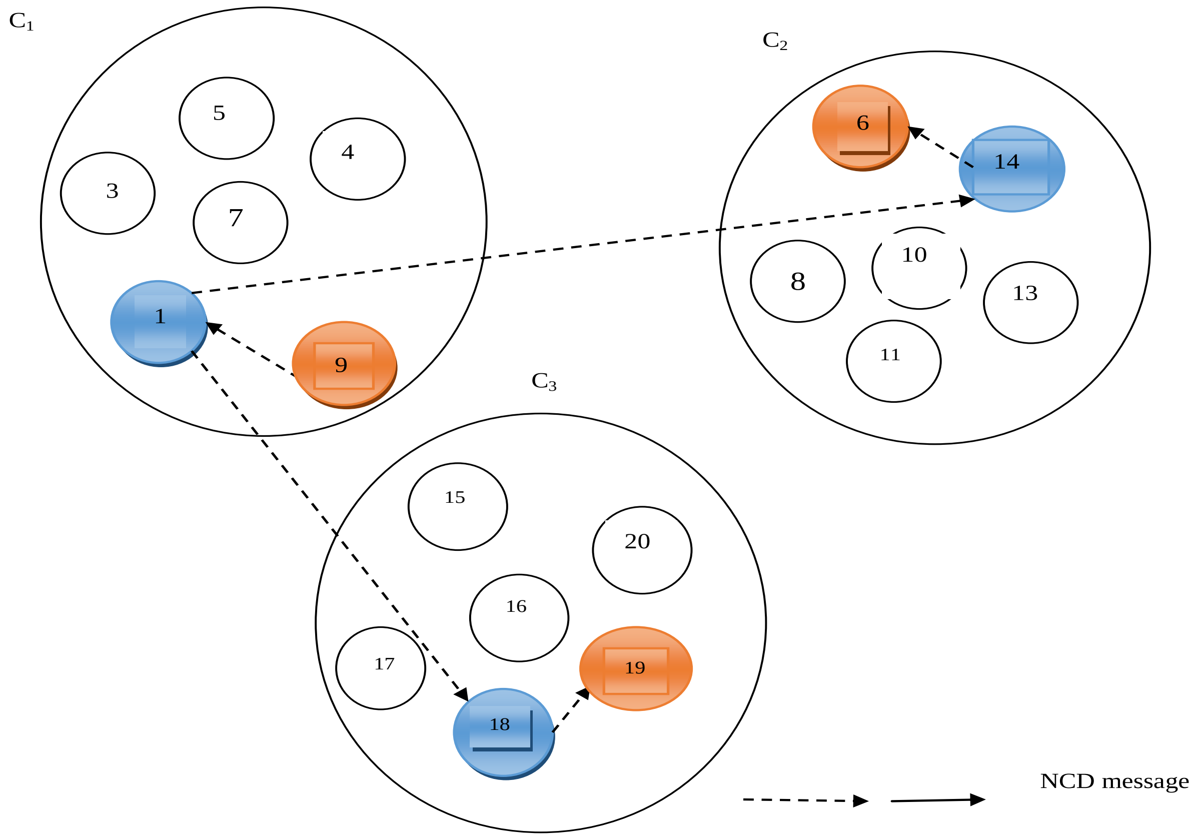

Fig.4. Broadcasting of NCD message.

C. Multi element routing protocol

After the clustering process, election of CH and creation of routing table by each network source connector, next step includes transmission of this information from source node to destination. The protocol considers various factors that provide better communication between source and destination node. “The FSO routing protocol using multielements [20] is shown in Fig. 5 is used for the transmission of data from source to destination so that they can achieve angular diversity and hence can cover multiple transceivers[3,9,10,20,21].”

Let S (Node No. 5) denote source node and D (Node No. 17) be the destination node.

τ represents set of network source connectors SCi.

The different steps involved in the process are explained as below:

Step 1: Source transmits the data based on data propagation model described to cover multiple receivers and provides clear LOS.

Step 2: The packet transmitted contains destination ID and sent to its respective network connector SCi called as local source connector (LSC)

[Data] [D_{Id}] [Data] [D_{Id}]

Source → CHi → SCi

Step 3: After that LSC verifies its local routing table

if LSC doesn't contain D Id

then

REQ DId

LSC → τ

End if

If any SCi within τ contains DId

then that SCi becomes destination network connector (DNC)

Info [D]

DNC → LSC

Step 4: After confirmation about ID of destination node, LSC sends data to DNC which in turn sends to destination finally.

[Data] [Data]

LSC → DNC → D

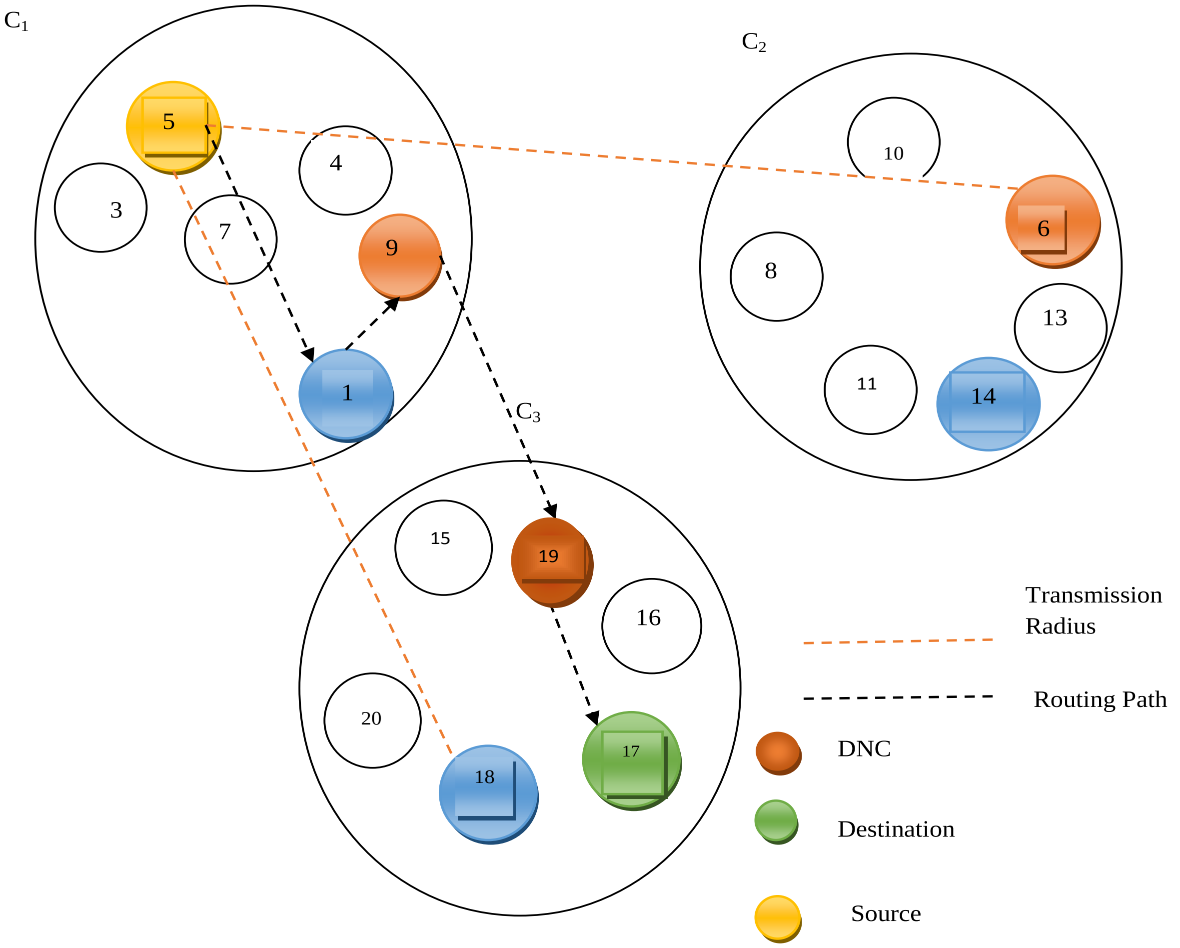

Fig. 5. Multi element routing protocol

Advantages:
High throughput and Clear LOS

III. SIMULATION RESULTS

A. Simulation Setup

The performance of the Hierarchical Routing protocol with Optical Sphere for Smooth Routing (HROS) is evaluated through NS-2[22] simulation. The FSO extensions[19] in NS-2 are used to run the simulation. The simulation can provide perceptive information on scaling behavior of FSO networks. The FSO extension to NS-2[22] includes the following features:

- In addition to the 3-D pointing and divergence angle features, directional FSO antenna model and the necessary fields denote the accompanied LED/transmitter and photo-detector components.
- For each transceiver, a mechanism for periodic establishment of alignment lists is used in case of uni-directional and bidirectional scenarios.
- The necessary source power is calculated by the FSO power calculator to send the packet of known size to a destination at a specified range.
- The estimation of received power depends on Gaussian distributed geometric beam spread and orientation of receiving photo-detector.
- The calculation of noise during transmission
- The error probability for given received power, visibility in the medium, separation of transmitter and receiver, atmospheric attenuation and noise heard during transmission can be calculated by FSO modulation mechanism.
- To evade the beams getting through the nodes and as well as distinguishing the nodes from obstacles simple obstacle simulation mechanism is utilized.
- A random network deployed in an area of flat grid with dimension 500 X 500m is considered. However, it is easily achievable to simulate spherical FSO nodes placed in three dimensional space as the antenna is represented in three dimensions. The number of nodes is varied as 25, 50, 75 and 100. The random way point (RWP)[3] mobility model is used for node mobility.

To determine the available alignments among the transceivers, a timer mechanism is implemented which is triggered off every half second. This mechanism contains identical design of multi-element [3,9,10,20,21] FSO node structure.

Table 4 summarizes the simulation parameters used.

TABLE 4 SIMULATION PARAMETERS

No. of Nodes	25,50,75 and 100
Area Size	2200 X 2200
Simulation Time	50 sec
Packet Size	512
Transmission Range	300m
Propagation Model	Free Space Optical
Antenna Type	FSOAntenna
Modulation Type	Binary Phase Shift Keying / FSO
No. of Interfaces	4
Node radius	20 cm

B. Performance metrics

The performance of HROS is compared with HCBR [8] protocol. The performance is evaluated mainly, according to the following metrics Average end-to-end Delay,Drop and Throughput Fig. 6 to 9 present the graphical representations of the results of delay, delivery ratio, packet drop and throughput, respectively.

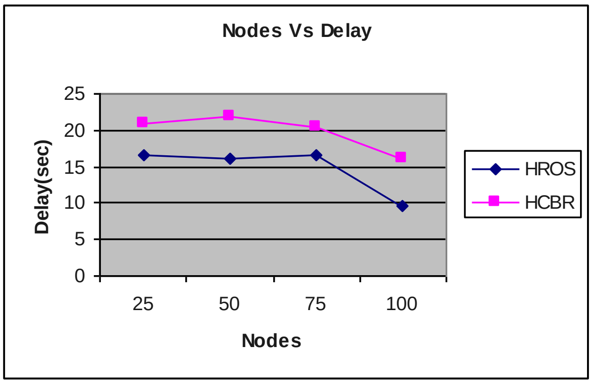

Fig. 6. Nodes Vs Delay

Fig. 6 shows by varying the mobile nodes the end-to-end delay occured in the network. From the figure, it can be seen that the end-to-end delay of HROS is 26% less than the existing HCBR protocol. This is due to the fact that since HROS uses spherical data propagation model, it achieves spatial reuse thereby avoiding the transmission delays.

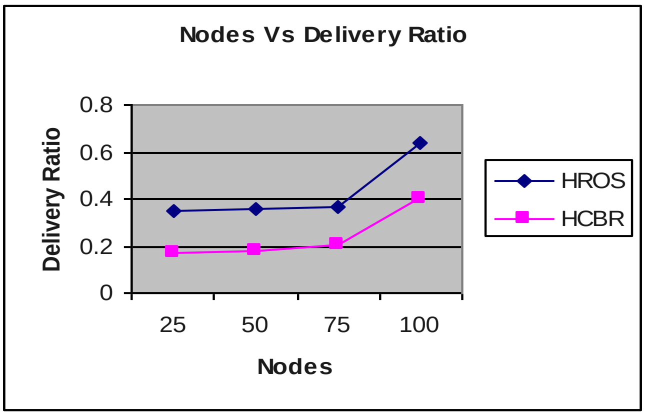

Fig. 7. Nodes Vs Delivery Ratio

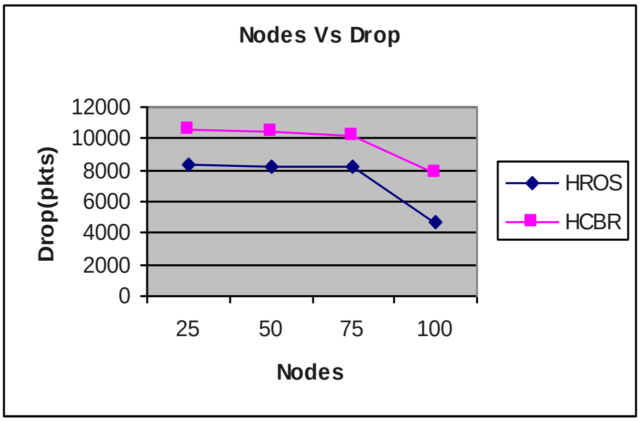

Fig. 8. Nodes Vs Drop

Fig. 7 and 8 shows the packet delivery ratio and packet drop, respectively, of both the protocols by varying the nodes. Since HROS provides spherical antennas for communications it maximizes the coverage and avoids frequent disconnetions. Hence it reduces the packet drops due to disconnections and cross-talk. From the figure, it can be seen that the delivery ratio of HROS is 45% high and packet drop is 25% less, when compared to HCBR, which contain single element non-spherical antenna.

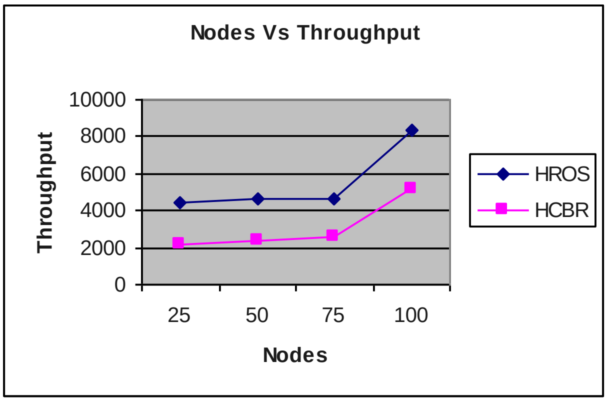

Fig. 9. Nodes Vs Throughput

From Fig. 9, it can be seen that the throughput of HROS is 45% higher than existing HCBR protocol, since HROS maximizes the coverage and avoids frequent disconnetions and cross-talk by using spherical antennas.

IV. CONCLUSION

In this paper, hierarchical routing protocol along with data propagation model is proposed to provide smooth routing protocol in FSO MANET. Here, first clustering process is done according to neighbor discovery algorithm and then CH is selected by network source connector. The node that is nearer to the network source connector is selected as CH. Each network source connector updates a routing table which contains information about each node in the cluster along with ID of the destination node. Also source transmits packet according to the data propagation model which covers a large transmission range. In order to provide clear LOS, proposed model considers parameters such as intensity of beam, divergence angle, geometric attenuation factor, and atmospheric attenuation factor that helps to provide consistent and reliable communication without any interruption in the network. From simulation results it can be seen that Delay is 26% less, Delivery Ratio is 45% more, Drop is 25% less and Throughput is 45% higher in the proposed HROS protocol than the existing HCBR protocol. Hence the advantage of proposed protocol is that it provides high throughput, clear LOS along the consistent performance of TCP.

REFERENCES

[1] J. Akella, C. Liu, D. Partyka, M. Yuksel, S. Kalyanaraman, and P. Dutta, "Building Blocks for Mobile Free-Space-Optical Networks," Proceedings of IFIP/IEEE International Conference on Wireless and Optical Communications Networks (WOCN), pp. 164–168, IEEE, (2005).

[2] SANS Institute InfoSec Reading Room, "Free-Space Optics: A Viable, Secure Last-Mile Solution?" © SANS Institute (2002).

[3] M. Bilgi and M. Yuksel, "Multi-Element Free-Space-Optical Spherical Structures with Intermittent Connectivity Patterns," Proc. IEEE Infocom Student Workshop, Phoenix, AZ, (2008).

[4] A. R. Mohd Shariff and M. E. Woodward, "A Delay Constrained Minimum Hop Distributed Routing Algorithm using Adaptive Path Prediction," Journal of Networks Vol.2, No.3, pp.46-57 (2007).

[5] G. Cheng and N. Ansari, "Finding All Hops Shortest Paths," IEEE Communication Letters, Vol.8, No.2, pp.122-124 (2004).

[6] Ziping Hu, Pramode Verma, and James Sluss Jr., "Routing in Degree-constrained FSO Mesh Networks ", International Journal of Hybrid Information Technology, Vol.2 ,No.2, (2009).

[7] A. R. Mohd Shariff, M. E. Woodward ," A Delay Constrained Minimum Hop Distributed Routing Algorithm using Adaptive Path Prediction", JOURNAL OF NETWORKS, Vol. 2, NO. 3, (2007)

[8] D.Kishore Kumar and Y.S.S.R.Murthy, "Hybrid Cluster based Routing Protocol for Free-Space Optical Mobile Ad hoc Networks", Springer (2013).

[9] Mehmet Bilgi , Murat Yuksel, "Multi- Transceiver Simulation Modules for Free- Space Optical Mobile Ad hoc Networks", Proc. SPIE 7705, (2010) [doi:10.1117/12.851756].

[10] Behrooz Nakhkoob, Mehmet Bilgi, Murat Yuksel, and Mona Hella, " Multi-Transceiver Optical Wireless Spherical Structures for MANETs" , IEEE Journal On Selected Areas in Communications, Vol. 27, NO. 9, (2009)

[11] M. Yuksel, J. Akella, S. Kalyanaraman, P. Dutta, "Free-space-optical mobile ad hoc networks: auto-configurable building blocks", ACM Springer Wireless Networks, Vol. 15 pp. 295–312 (2009)

[12] Mehmet Bilgi , Murat Yuksel," Capacity scaling in free-space-optical mobile ad hoc networks", Published by Elsevier Ad Hoc Networks, Vol. 12 , pp.150–164, (2014)

[13] W. Di, A. Alhussein, "Throughput and delay analysis for hybrid radiofrequency and free-space-optical (RF/FSO) networks", Springer Wireless Networks , Vol.17, pp. 877–892 (2011)

[14] Jason Derenick, Christopher Thorne and John Spletzer, "On the Deployment of a Hybrid Free-space Optic/Radio Frequency (FSO/RF) Mobile Ad-hoc Network", IEEE/RSJ International Conference on Intelligent Robots and Systems, (2005).

[15] Abhishek Kashyap, Anuj Rawat and Mark Shayman, "Integrated Backup Topology Control and Routing of Obscured Traffic in Hybrid RF/FSO Networks", IEEE Globecom, (2006)

[16] Bow-Nan Cheng , Murat Yuksel , Shivkumar and Kalyanaraman, "Using Directionality in Mobile Routing ", IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS), (2008).

[17] Unoma Ndili Okorafor and Deepa Kundur, "Efficient Routing Protocols for a Free Space Optical Sensor Network", IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS) , pp. 251 – 258, IEEE, Washington DC(2005).[doi: 10.1109/MAHSS. 2005. 1542807]

[18] D.Kishore Kumar and Y.S.S.R.Murthy, "Hierarchical Routing Protocol for Free-Space Optical Mobile Ad hoc Networks (FSO/RF MANET)", International Journal of Computer Applications (0975 – 8887) Vol. 60, No.10, (2012)

[19] M. Bilgi, M. Yuksel, "Packet-based simulation for optical wireless communication", Proceedings of IEEE Workshop on Local and Metropolitan Area Networks, IEEE, (2010).

[20] Kavitha Balamurugan,K Chitra, A Jawahar "Enhanced Heirarchical Cluster Based Routing Protocol with Optical Sphere in FSO MANET", Vol. 468, pp.1-8, 2017/11/25.

[21] Asaad Kaadan, Hazem H. Refai, Peter G. LoPresti, "Multielement FSO Transceivers Alignment for Inter-UAV Communications", JOURNAL OF LIGHTWAVE TECHNOLOGY, Vol. 32, NO. 24, (2014).

[22] Network simulator, http://www.isi.edu/nsnam/ns