

## Performance Enhancement of MANET based on Cross-layered Reconfigurable Hierarchical Routing Protocol

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High speed data communication is the demanding factor in both commercial and defence applications. Several algorithms are proposed to support the high-speed data exchange while ensuring the quality, performance and reliability. However, there is still a gap, citing various compatibility issues with variety of transceiver technologies. This paper proposes a novel algorithm for enhancing the performance of mobile ad-hoc networks using Free-Space Optics (FSO). The FSO has the natural ability to the interference while capable of large bandwidth and excellent compatibility. Low power and adaptability are the features with which it has contributed to the latest technologies like storage area network, wireless area network etc. The proposed work uses optical spheres with a multi-transceiver system and a cross-layered reconfigurable routing mechanism. Parameters such as delay, residual energy, throughput, and drop are verified for the Crosslayered Reconfigurable Hierarchical Routing Optical Sphere (CRHROS) protocol for varying numbers of optical transceivers. The proposed work also compares the performance of two traffic sources, Constant Bit Rate (CBR) and Variable Bit Rate (VBR), for the proposed algorithm.

**Keywords:** Free-space optics, Mobile ad hoc network, Optical sphere, Routing protocol

### Introduction

In the recent past, the Free-Space Optics (FSO) has been gaining importance in domains where high-speed data communication is required. FSO exhibits attractive features such as immunity to electromagnetic interference, dense spatial reuse, ease of installation, low initial investment, secure system, high bandwidth, and relatively lesser power consumption.<sup>1-10</sup> With these salient characteristics, FSO finds a major part in outdoor wireless access, storage area network, fiber back-up, bridging wireless area network access, military access, and backhaul systems. The FSO offers several advantages. However, it suffers from some specific real-time challenges. The challenges are the Line of Sight (LOS), losses due to temperature variations (scintillation), absorption, and various atmospheric turbulences. Data communication FSO network is greatly affected by variations in atmospheric weather conditions like the presence of fog, rain, haze, smoke, sandstorms, and snow.

Researchers continuously explore novel methodologies to overcome the challenges mentioned above to make FSO-based wireless networks highly efficient. An OFDM-FSO transmission link can incorporate Optical Single Side Band (OSSB) and Optical Tandem Side Band (OTSB) Schemes.<sup>2,11-16</sup> This hybrid technique improves signal metrics like signal to noise ratio and bit error rate. With the hybridization of techniques, it is possible to achieve data rates as high as 5 Gbps even under severe weather conditions. In FSO-MANET, data transfer between the source and destination node relies on routing protocols. In general, ad-hoc routing protocols are categorized as Flat, Hierarchical routing, and Geographic position-assisted routing based on the commands given to nodes on routing data packets between computing devices within a mobile ad-hoc network.<sup>3, 17-23</sup> The proposed work adopts optical spheres with multiple transceiver models to facilitate uninterrupted LOS communication. To enhance performance characteristics like delay, residual energy, drop and Packet Delivery Ratio (PDR), a hybrid protocol based on hierarchical routing with the cross-layered reconfigurable model with

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optical spheres is proposed and analyzed in this research work.

**Proposed Algorithm**

The proposed CRHROS algorithm focuses on maintaining connectivity between nodes in a dynamically varying FSO-MANET that encounters problems such as loss of LOS and node energy depletion.<sup>4-7</sup> Maintaining connectivity (LOS) is achieved using optical spheres with multiple transceivers. A cross-layer based reconfigurable model is applied in a hierarchical routing algorithm to overcome the issues faced by energy depletion in nodes. In this approach, the node that faces a shortage of energy below a threshold level initiates reconfiguration while routing. Since energy depletion is verified in the network layer and the transceiver's positioning is overlooked in the link layer, the proposed protocol is cross-layer based reconfigurable routing. The Fig. 1 shows the methodology of the proposed CRHROS Protocol

Initially, FSO-MANET's cluster is organized based on Neighbourhood Discovery Algorithm (NDA). The routing table is created with the help of a network source connector based on the information gathered from the cluster head.

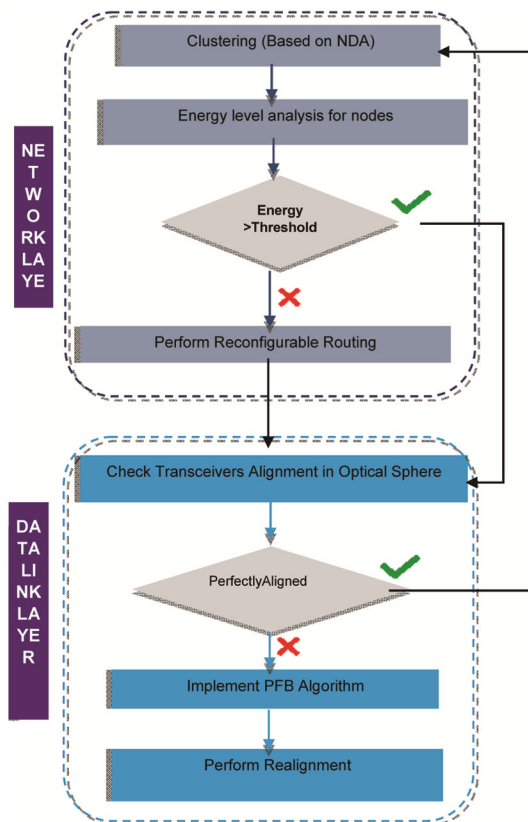


Fig. 1 — Methodology of Proposed CRHROS Protocol

**Clustering**

NDA defines the clustering process. Node<sub>j</sub> is taken to be the nodes available in the network.<sup>8-10</sup> (where j = 1, 2, 3, ..., l). Node<sub>nbh</sub> is the neighbour node, CL<sub>j</sub> is the cluster, and CHead<sub>j</sub> is the cluster head. Node (C<sub>j</sub>) is the Cluster node, and SConnect<sub>j</sub> is a connector that virtually connects the cluster members and networks in a hybrid fashion. The T is threshold that represents the maximum number of nodes that can join a network.

In the clustering process, SConnect<sub>j</sub> broadcasts a WELCOME message to Node<sub>nbh</sub> using NDA. The WELCOME content has source node identity number, source information (e.g. residual energy), and information about neighbours. As soon as the Node<sub>nbh</sub> gets the WELCOME message, it checks whether its ID is in the message. If it is present, Node<sub>nbh</sub> joins SConnect<sub>j</sub> in the cluster. It is repeated until a threshold to join the cluster is reached. For more than one WELCOME message, Node<sub>nbh</sub> decides to join a cluster on its own. In case, Node<sub>nbh</sub> gets WELCOME from many nodes, then Node<sub>nbh</sub> decides on SConnect<sub>j</sub> that has maximum energy. The CHead<sub>j</sub> is selected as the node closer to SConnect<sub>j</sub>. SConnect<sub>9</sub> broadcasts WELCOME messages to Node<sub>nb1</sub>, Node<sub>nb3</sub>, Node<sub>nb5</sub>, Node<sub>nb7</sub>, Node<sub>nb10</sub>, and similarly, Node<sub>C6</sub> and Node<sub>C19</sub>.

When the clustering process is done, the node near the connector is selected as CHead (Fig. 2). In Cluster<sub>1</sub>, Node<sub>1</sub> is taken as CHead because it is next to SConnect<sub>9</sub> and Node<sub>14</sub> and Node<sub>18</sub> is selected as CHead of Cluster<sub>2</sub> and Cluster<sub>3</sub> respectively.

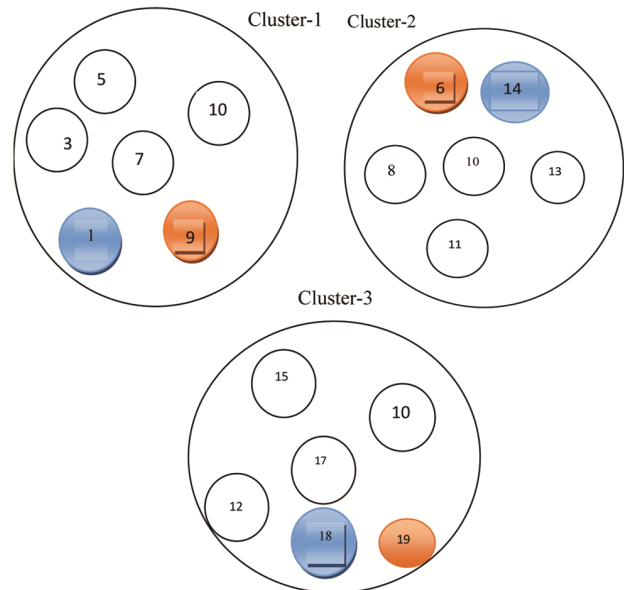


Fig. 2 — Cluster Head Election

**Reconfigurable Route Establishment Algorithm**

X is the source, Y is the destination, D\_Msg is the dying notification message, R\_Msg is the message for route change, PA and NA is the acknowledgment for positive and negative message. RRC\_Mes is defined as the notification for route reconfiguration. NodeB is defined as the Node buffer. In a random way as set in the routing table, X transmits data packet to Y, from its next hop. When time 't' elapses, cluster member energy level (ClustM<sub>j</sub>) to reach the destination is below the threshold, it is likely to get lost. The Ener<sub>th</sub> is initialized during the simulation. Cluster head CHead<sub>j</sub> will transmit D\_Msg to X. X on receiving D\_Msg, it does route change process explained as follows:

If an alternate CHead<sub>1</sub> exists towards Y, then CHead<sub>j-1</sub> can change their next hop node to CHead<sub>j</sub> otherwise, X sends RC\_Msg to ClustH<sub>j-1</sub> as in Eq. (1).

$$X \xrightarrow{RC\_Msg} ClustH_{j-1} \quad \dots (1)$$

CHead<sub>j</sub> on receiving RRC\_Msg has to adjust their orientation and radius of transmission (The orientation adjustment will direct packet transmission to cluster head). The usual data movement from ClustM<sub>5</sub> to ClustM<sub>15</sub> has been shown in Fig. 3. When CHead<sub>2</sub> fails, the changed path ClustM<sub>5</sub> to ClustM<sub>15</sub> is shown.

The data movement from ClustM<sub>5</sub> source to ClustM<sub>15</sub> destination is

[ClustM<sub>5</sub>, CHead<sub>1</sub>, SConnect<sub>1</sub>, SConnect<sub>2</sub>, CHead<sub>2</sub>, SConnect<sub>3</sub>, CHead<sub>3</sub>, ClustM<sub>15</sub>].

Due to energy drop if CH<sub>2</sub> fails, it is possible to transfer the packet via modified path that is in the routing path as

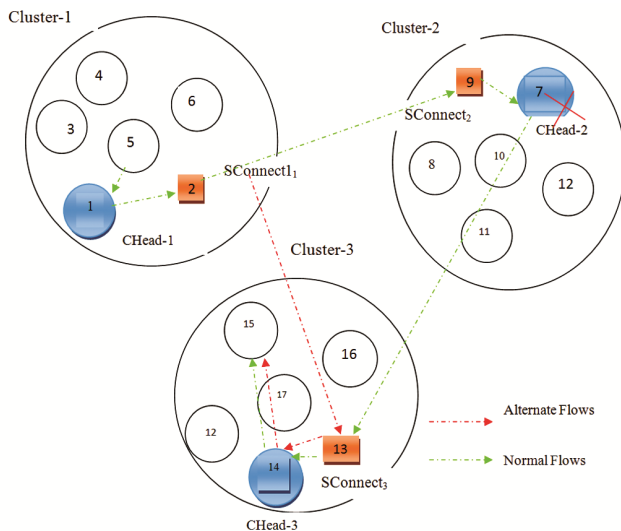


Fig. 3 — Reconfiguration of route

[ClustM<sub>5</sub>, CHead<sub>1</sub>, SConnect<sub>1</sub>, SConnect<sub>3</sub>, CHead<sub>3</sub>, ClustM<sub>15</sub>].

If the alternate path is not present, then data is directly transmitted to ClustH<sub>3</sub> when ClustM<sub>5</sub> alters its orientation and radius.

**Transmission using Route Re-configuration**

X transmits the packets using re-configured route. Respective protocol sends data packet to link layer that further verifies the alignment of interfaces. If there is alignment, Link Layer puts the packet in the queue. Flow buffer algorithm<sup>4</sup> is used by the link layer if no alignment is found. This is followed by realignment. As the first step, interface alignment is checked. If interface exists, the packet is moved to the link layer else the packet moves to the node buffer. If node buffer is full, link layer sends negative acknowledgement and source checks changed route. The link layer will send Negative ACK, if Node Buffer is packed fully.<sup>20</sup> On receiving this NACK message, the source will verify an alternate path.

**Performance Analysis**

The veracity of the proposed CRHROS performance is established through NS2 simulation. The simulation is done with number of nodes equal to 100 for multiple elements. Simulation parameters adopted for analysing the performance of the proposed algorithm are given in Table 1. CBR with a rate of 512 bytes per packet is preferred over Variable Bit Rate (VBR), as it offers greater compatibility with most systems with added

Table 1 — Simulation parameters

Parameter	Value(s)
Nodes	100
Number of flows	49 × 48
No. of transceivers	4, 6, 8, 10, 12, 14
Area	2200 m × 2200 m
Radius of node	20 cm
Angle of divergence	1 rad
Diameter of PD	5 cm
Diameter of LED	0.5 cm
Mac	802.11
Simulation time	50 sec
Mobility	1 m/s
Traffic source	CBR
Size of packet	512 bytes
Medium visibility	6 km
Transmission range	500 m
Transmission rate	250 Kbps
Propagation model	FSO sphere
Antenna type	FSO antenna with multi transceivers
Modulation	BPSK

feature of predicting the file size. BPSK is preferred for modulation because BER performance is better than OOK and DPSK schemes and offers high channel capacity compared to other modulation techniques. Hence, BPSK modulation is considered the most favourable modulation technique for FSO system, effectively reducing turbulence.<sup>11</sup> Mobility scenarios are generated using Random Way-Point (RWP) model.<sup>12</sup> While roaming, NS-2 simulator RWP is used to find the node movement, providing good throughput results in mobile cases such as vehicular and naval networks and also as the node mobility is small.

Specific mobility model selection can affect the simulation results. An ad hoc network simulation is based on two mobility models known as Traces model and Synthetic model.<sup>13</sup> In the former case, the mobility pattern is observed in the form of traces in real-time, whereas in the synthetic model, realistic behaviour is provided for mobile nodes without the use of traces.

Random Way Point (RWP) mobility model is a class of synthetic model in which the movement of nodes is focused onto the middle of a simulation area, as nodes may bounce back on reaching the network boundary. An ad hoc network protocol can provide the correct response in a dynamic environment. As the nodes change their position continuously, modelling users' movement is required in such a dynamic network. Several parameters like initial assignment of nodes, mobility nature of nodes, number of nodes present totally, and the selection of mobility models is to be considered during computational analysis. The mobility aspect is an excellent challenge for FSO networks that need a clear LOS. The proposed work analyses parameters such as delivery ratio, delay and drop. Achievement of better throughput with speed up to 20 m/sec is observed.

**Results and Discussion**

**Transceiver Performance**

Performance of proposed CRHROS is analysed with 4, 6, 8, 10, 12 and 14 transceivers. The concerned parameters of interest are delay, PDR, PD and residual-energy. The End-to-End delay typically is of the order of milliseconds. This is typically measured as the time consumed by the data packets while moving from source to destination.<sup>14</sup>

The end-to-end delay in network by varying the number of elements in the transceivers is explained in Fig. 4(a). The decrease in the delay is 0.0513 per

transceiver with a linearity of 0.9757 due to rapid alignment and the delay involved in route discovery process. The delay becomes lesser, when the number of transceivers increases from 4 to 14. There is a decrease in delay by 12%. This is due to the alignment which consequently shrinks the route discovery process.

The Packet Delivery Ratio (PDR) is the number of packets delivered to the destination successfully to the total number of packets generated at the source node.<sup>15</sup> The Fig. 4(b) shows the PDR of CRHROS through variations in the number of transceivers. As the number of transceivers increases from 4 to 14, PDR increases at a rate of 0.0184 per transceiver with linearity of 0.986. The characteristic is due to an increase in the reception of successful data packets with the number of effective transceivers in the optical spheres. A factor of 7% increases PDR as the number of successful packets received becomes more.

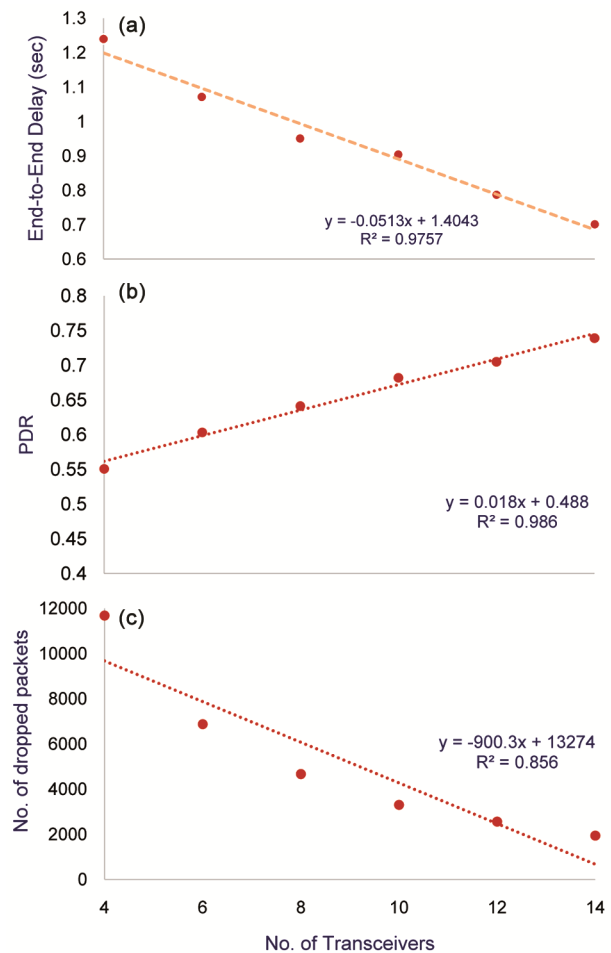


Fig. 4 — Transceiver performance: (a) Performance of delay concerning transceivers; (b) PDR vs No. of transceivers (c) Dropped Packets vs No. of Transceivers

The Packet Drop (PD) factor represents the number of packets dropped (failed) during data transmission.<sup>16</sup> As per Fig. 4(c), the PD decreases with the number of transceivers. The increase rate is 900.3 per transceiver with linearity of 0.856. When the number of transceivers increases, alignment becomes better and the drop drops correspondingly less. PD falls by 36% as a greater number of transceivers enhance the propagation. When the source transmits packets using the proposed data propagation model, the transmission range is increased and the line of sight becomes clear for routing in FSO.

But the number of transceivers cannot keep increasing beyond 14, as the transmission gets detected by a wider number of neighbours receivers in the vicinity of the transmitter. Adjacent beams may overlap resulting in interference. Further increase in the number of transceivers may result in cost overhead;

hence, there is a trade-off between cost and performance metrics.

**Comparison of Network Traffic Models**

The analysis is further extended to compare the performance parameters of proposed CRHROS with standard PFB protocol for two traffic sources: CBR and VBR. This computation is carried out by varying number of nodes from 25 to 100.

The delay measured for CRHROS and PFB for increasing number of nodes from 25 to 100 is shown in Fig. 5(a). End-to-end delay reported in CRHROS is 78% lesser than that of PFB. Similarly, Fig. 5(b) and Fig. 5(c) shows measured PDR and packet drops respectively. From the Fig. 5(b) and Fig. 5(c), it is inferred that the proposed algorithm outperforms PFB when number of nodes increases. The residual energy for CRHROS and PFB for different number of nodes is self explanatory in Fig. 5(d). During transmission, energy remaining within a node is termed residual energy which is expressed in milli Joules (mJ). The residual energy of CRHROS rises from 7.57 to 8.03 joules and residual energy of PFB rises from 3.81 to 4.03 joules as the number of nodes increases from 25 to 100.

**Conclusions**

The proposed CRHROS algorithm enhances end-to-end delay, PDR, PD, and residual energy. Delay reduced to 0.0513 per transceiver with linearity of 0.9757. While transceiver count is enhanced from 4 to 14, the corresponding PDR follows the same trend at a rate of 0.0184 per transceiver with linearity of 0.986 using the proposed methodology. Similarly, the PD diminishes with an increase in the number of transceivers at a rate of 900.3 per transceiver. Comparison between CBR and VBR traffic models also shows enhanced performance for the proposed CRHROS method, which can be applied for FSO networks to uplift the overall efficiency of an ad-hoc MANETs. The best future work is the performance analysis in the proper two-fold form, considering implementation and developing the logical structure.

**Abbreviations**

- CRHROS Cross-layered reconfigurable hierarchical routing optical sphere
- FSO Free space optics
- HCBR Hierarchical cluster based routing
- HRP Hierarchical routing protocol
- HRPOS Hierarchical routing protocol with optical sphere
- NS Network simulator
- PFB Per flow buffer
- RWP Random way point
- VBR Variable bit rate

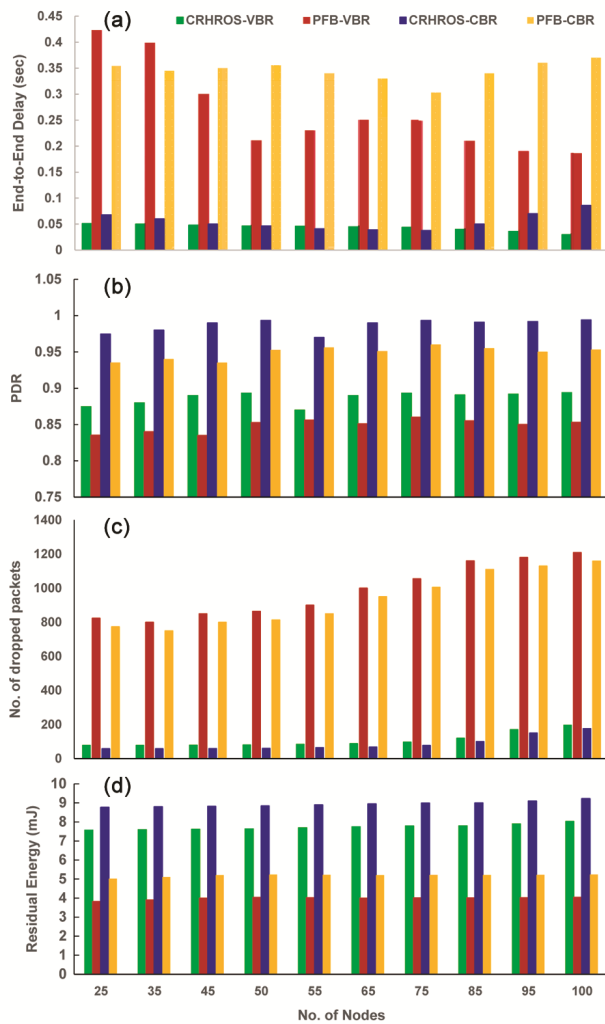


Fig. 5 — Response of different parameters against number of nodes: (a) Delay vs no. of nodes; (b) PDR vs no. of nodes; (c) Dropped packets vs no. of nodes; (d) Residual energy vs no. of nodes

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