Neighbor Discovery in a Multi-Transceiver Free-Space-Optical Ad Hoc Network

Jessica Vazquez-Estrada*, Suman Bhunia*, Mahmudur Khan†, Yicheng Qian*, and Nero Tran Huu*
* Department of Computer Science and Software Engineering, Miami University, Oxford, Ohio
† Electrical & Computer Engineering and Computer Science Department, York College of Pennsylvania, York, Pennsylvania
Email: vazqueje@miamioh.edu, bhunias@miamioh.edu, mkhan17@ycp.edu, qiany21@miamioh.edu, tranhuq@miamioh.edu

***Abstract*—In this paper, we present a novel neighbor discovery method for a wireless ad hoc network where each node is equipped with a Free-Space-Optical (FSO) transceivers capable of electronic beam switching. Directional neighbor discovery can be very challenging due to the requirement of strict line-of-sight (LOS) alignment and can result in long and impractical discovery time if the nodes in the network do not have prior information about each other's location. Our method guarantees that a node can discover all of its neighbors within one 360° FSO beam sweep. We present a preliminary prototype of a FSO transceiver module capable of electronic beam steering. Through experiments using the developed prototype, we demonstrate that the proposed method helps in discovering neighbor nodes with minimal delay.**

***Index Terms*—Free-Space-Optical communication, Directional Communication, Neighbor Discovery, Line-of-Sight.**

I. Introduction

The demand for high speed wireless data transfer rates has grown significantly in the last few decades. Traditional radio frequency (RF)-based omnidirectional communication systems such as WiFi or cellular communication cannot achieve such high speed communication. In this context, directional communication such as FSO, millimeter-wave and terahertz communication have demonstrated the potential to help solve the problem of high data rate requirement [1]–[3]. FSO communication (FSOC) has gained an increase in interest due to its high-speed data transfer rate in conjunction with with its low-cost. FSOC networks can be valuable for military and security applications due to their invulnerability to interference, making them immutable to active attackers. Moreover, higher spatial reuse can help in establishing multiple parallel communication links with different neighbor nodes and thus enable much larger bandwidth compared to RF.

Despite the advantages of FSOC, due to the strict requirement of LOS alignment, neighbor discovery can be very challenging in such highly directional networks. Oblivious discovery protocols assume that the nodes in the system have no prior knowledge regarding their neighbors' location. Such asynchronous algorithms based on unique identification (ID) numbers have been proposed in [4], [5] for nodes with mmWave transceivers. Although these methods ensure discovery within a bounded time period, the average discovery delay is too long. Studies have been made in attempt to reduce these discovery times by developing discovery protocols that are assisted by low bandwidth omnidirectional technology [6].

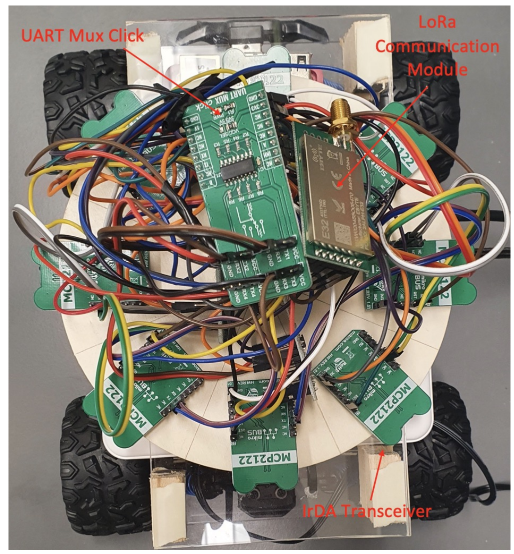

Fig. 1: Prototype with IrDA transceivers, LoRa module and Raspberry Pi as the controller.

In this paper, we present a neighbor discovery method for a 2D ad hoc network that does not require GPS-clock synchronization and ensures both bounded and minimal discovery times. Coordination and spatial awareness of the nodes is directed by an omni-assisted long range LoRa channel [7]. We developed a prototype where each node is equipped with multiple highly directional FSO transceivers. Each node can electronically steer its FSO beam by switching from one transceiver to another to scan the surrounding 360° space. We demonstrate the effectiveness of our proposed method through real test-bed experiments using the prortotype.

II. Neighbor Discovery Method

A. Discovery Initialization using LoRa

In the initialization phase, each node initiates the communication by through the supplementary omnidirectional channel to send an request-to-send (RTS) beacon message. If a neighbor node exists in the vicinity, upon receiving the RTS, the neighbor sends back a clear-to-send (CTS) acknowledgement.

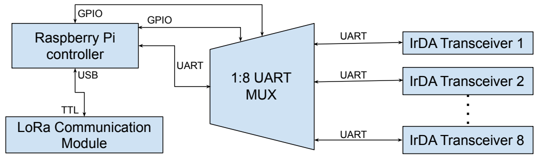

Fig. 2: Schematic diagram of the developed prototype.

Once the existence of a neighboring node is found, the LOS neighbor discovery process can begin.

B. LOS Discovery

In the LOS neighbor discovery phase, the Leader node begins scanning by activating the transceiver facing north and transmitting a beacon message. It transmits a *Hello* beacon through FSO transceiver and wait for *H-Ack* for a wait period. If it does not receive any *H-Ack*, it switches to the adjacent transceiver in a counter-clockwise fashion, hence the term electronic switching/steering. Similarly, the Follower node activates its transceiver facing south for a wait period and repeats the process for the adjacent transceivers. The Leader continuously sends a *Hello* message in the direction it is transmitting and waits for a response. The Follower waits to receive the *Hello* message. Once the beams are aligned (i.e., the transceivers face each other in LOS), the *Hello* message can be received by the Follower and it will stop scanning. The Follower then sends an *H-Ack* message back to the Leader. When the Leader successfully receives an *H-Ack* message in return, it also stops scanning. Finally, the Leader sends a last acknowledgment message, *Ack*, back to the Follower. The completion of this three-way handshake confirms that neighbor discovery is complete.

III. Proof-of-concept Prototype and Evaluation

A. Prototype

We built a proof-of-concept prototype of the multi-transceiver FSO communication module using off-the-shelf hardware and electronic components. Fig. 1 and Fig. 2 depicts the top view and the schematic diagram our developed prototype. We implemented the neighbor discovery protocol using python[1]. The system prototype consists of eight IrDA transceivers [8], three UART multiplexers, a LoRa [7] communication module, and one Raspberry Pi as the controller. The IrDA transceivers are connected to the MUX through UART. The data path is completely controlled through four GPIO ports of the Raspberry Pi. The LoRa communication module can communicate directly with the USB port of the Raspberry Pi. It connects to the serial USB port of the Raspberry Pi via a USB to TTL converter.

B. Experiment results

We conducted real test-bed experiments using our developed multi-transceiver FSO module prototype to assess the effectiveness of our proposed neighbor discovery method. We used two identical nodes and placed them at random positions with respect to each other. We repeated the experiment for 110 times, placing the nodes at a different positions each time. The neighbor discovery time for each iteration is plotted in Figure 3. Note that we are using UART-based serial communication for sending packets through IRDAs. To tackle the delays associated with the MUX, IRDA, etc., we force the nodes to wait for 160 ms before switching to the next IRDA. This makes the three-way-handshake time higher. The average time for discovery over all the iterations is ≈ 2.985 seconds.

[1]The code is available at https://github.com/wsl-miami/nd-system

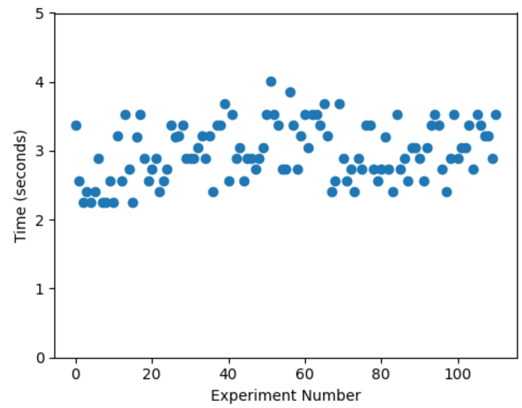

Fig. 3: Neighbor discovery time for each iteration of the experiment.

IV. Conclusion

We proposed a novel method for neighbor discovery with the help of a long-range low-bit rate omnidirectional helper communication channel. Through experiments using our developed proof-of-concept prototype we demonstrated that the proposed protocol can achieve guaranteed neighbor discovery with minimal delay. We plan to extend the work by incorporating the effect of packet collision while discovering multiple neighbor nodes.

References

[1] J.-H. Lee, K.-H. Park, Y.-C. Ko, and M.-S. Alouini, “A UAV-mounted free space optical communication: Trajectory optimization for flight time,” *IEEE Transactions on Wireless Communications*, vol. 19, no. 3, pp. 1610–1621, 2019.

[2] S. Ghafoor, N. Boujnah, M. H. Rehmani, and A. Davy, “MAC protocols for terahertz communication: A comprehensive survey,” *IEEE Communications Surveys & Tutorials*, vol. 22, no. 4, pp. 2236–2282, 2020.

[3] Y.-N. R. Li, B. Gao, X. Zhang, and K. Huang, “Beam management in millimeter-wave communications for 5G and beyond,” *IEEE Access*, vol. 8, pp. 13282–13293, 2020.

[4] L. Chen, Y. Li, and A. V. Vasilakos, “On oblivious neighbor discovery in distributed wireless networks with directional antennas: Theoretical foundation and algorithm design,” *IEEE/ACM Transactions on Networking*, vol. 25, no. 4, pp. 1982–1993, 2017.

[5] Y. Wang, S. Mao, and T. S. Rappaport, “On directional neighbor discovery in mmwave networks,” in *2017 IEEE 37th international conference on distributed computing systems (ICDCS)*, pp. 1704–1713, IEEE, 2017.

[6] M. Khan, S. Bhunia, M. Yuksel, and L. C. Kane, “Line-of-sight discovery in 3D using highly directional transceivers,” *IEEE Transactions on Mobile Computing*, vol. 18, no. 12, pp. 2885–2898, 2018.

[7] “LoRa E32-TTL-100 433T20DC SX1278 433 MHz 433MHz UART Long Range 1000w Wireless RF Module.” https://img.filipeflop.com/files/download/E32_User+Manual_EN_v1.00.pdf.

[8] “IRDA 3 CLICK.” https://www.mikroe.com/irda-3-click.