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Article

A Hybrid Approach to Neighbour Discovery in Wireless Sensor Networks

Sagar Mekala[1,*] and K. Shahu Chatrapati[2]

[1]Department of CSE, Mahatma Gandhi University, 508003, Telangana State, India
[2]Department of EEE, JNTUH College of Engineering Manthani, 505212, Telangana State, India
*Corresponding Author: Sagar Mekala. Email: arjunnannhi5@hotmail.com
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Abstract: In the contemporary era of unprecedented innovations such as Internet of Things (IoT), modern applications cannot be imagined without the presence of Wireless Sensor Network (WSN). Nodes in WSN use neighbour discovery (ND) protocols to have necessary communication among the nodes. Neighbour discovery process is crucial as it is to be done with energy efficiency and minimize discovery latency and maximize percentage of neighbours discovered. The current ND approaches that are indirect in nature are categorized into methods of removal of active slots from wake-up schedules and intelligent addition of new slots. The two methods are found to have certain drawbacks. The first category disturbs original integrity of wake-up schedules leading to reduced chances of discovering new nodes in WSN as neighbours. When second category is followed, it may have inefficient slots in the wake-up schedules leading to performance degradation. Therefore, the motivation behind the work in this paper is that by combining the two categories, it is possible to reap benefits of both and get rid of the limitations of the both. Making a hybrid is achieved by introducing virtual nodes that help maximize performance by ensuring original integrity of wake-up schedules and adding of efficient active slots. Thus a Hybrid Approach to Neighbour Discovery (HAND) protocol is realized in WSN. The simulation study revealed that HAND outperforms the existing indirect ND models.

Keywords: Wireless sensor networks; neighbour discovery; hybrid method; energy efficiency; wake-up schedules

1 Introduction

In the contemporary era of unprecedented innovations such as Internet of Things (IoT), modern applications cannot be imagined without the presence of Wireless Sensor Network (WSN). Nodes in WSN use neighbour discovery (ND) protocols to have necessary communication among the nodes. Neighbour discovery process is crucial as it is to be done with energy efficiency and minimize discovery latency and maximize percentage of neighbours discovered.

From the literature, it is understood there are many ND protocols. With respect to indirect ND protocols, there are two important groups. One group of protocols focused on adding new active slots in wakeup schedules while the other category removed certain active slots. The first category disturbs original

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integrity of wake-up schedules leading to reduced chances of discovering new nodes in WSN as neighbours. When second category is followed, it may have inefficient slots in the wake-up schedules leading to performance degradation. Therefore, the motivation behind the work in this paper is that by combining the two categories, it is possible to reap benefits of both and get rid of the limitations of the both. Our contributions in this paper are as follows.

1. We proposed a Hybrid Approach to Neighbour Discovery (HAND) protocol which combines two indirect ND methods to reap benefits of them besides overcoming their existing limitations.
2. We proposed an algorithm to realize the notion of virtual node its mechanisms to ensure performance improvement in the HAND protocol.
3. We have built a simulation prototype to evaluate the HAND protocol and its underlying mechanisms in ND.

The remainder of the paper is structured as follows. Section 2 reviews literature on existing ND methods. Section 3 presents the HAND protocol. Section 4 presents experimental results. Section 5 concludes the paper and gives information about future scope of the research.

2 Related Work

Different ND protocols and related works are found in the literature. Kumar et al. [1] studied the WSNs associated with IoT use cases for ascertaining ND challenges. Elhabyan et al. [2] focused on the ND coverage protocols associated with WSN. Deng et al. [3] investigated on the methods used for energy efficiency in the field environment. Zhou et al. [4] studied services in WSN for improving concurrent compositions. Yi et al. [5] focused on WSN usage is real world applications such as pollution monitoring. Xie et al. [6] on the other hand explored data collection methods for WSN. Li et al. [7] and Lius et al. [8] focused on vegetable greenhouses and industrial monitoring with enhanced performance using WSNs. Wei et al. [9] proposed and discussed many fast ND algorithms. Almeida et al. [10] explored fractal clustering and Pearson correlation for enhancing lifetime of WSN. Chen et al. [11] investigated mobile sensing applications to observed ND mechanisms. Lee et al. [12] focused on asynchronous wake schedules in WSN using Prime Block Design (PBD). Bakht et al. [13] discussed about the working of ND protocol known as Searchlight.

Wei et al. [14] explored a ND protocol for IoT using probabilistic neighbourhood model for leveraging performance. Zhang et al. [15] focused on generic approaches that could improve ND performance in mobile sensor applications. Zhang et al. [16] explored EQS systems on ND and rendezvouses maintenance. Chen et al. [17] proposed a prime set based approach towards ND for low duty cycled WSN. Wei et al. [18] built an efficient ND protocol for low duty cycled WSN. Lai et al. [19] proposed a wake scheduling mechanism based on heterogeneous quorum. Another quorum based approach is proposed by Own et al. [20] with weighted approach besides rendezvous consistency. Kandhalu et al. [21] proposed U-connect, an ND protocol while Meng et al. [22] proposed code based ND protocol. Chen et al. [23] focused on asynchronous neighbour discovery for mobile sensor devices. Similar kind of work carried out by Chen et al. [24] while Kindt et al. [25] proposed yet another protocol named Griassdi for ND. Qui et al. [26] proposed an energy efficient ND while similar kind of work is carried out by Suarez et al. [27]. Cai et al. [28] proposed ND protocol based on quorum and self-adaptive in nature. Device discovery in mobile computing environments is studied in [29] and [30].

Other important approaches found in the literature include ND for mobile WSN [31,32], RSSI for distance measure [33], self-adaptive ND [34], proactive ND for mobiles [35], ND with slot length control [36], ND with multi-packet reception model [37], ND model known as Panacea [38], prime number based ND [39] and group based ND [40]. Secure critical data reclamation methods for isolated clusters in WSN proposed [41,42]. From the literature, it is understood there are many ND protocols. With respect to indirect ND protocols, there are two important groups. One group of protocols focused on adding new active slots in wakeup schedules while the other category removed certain active slots. The first category disturbs original integrity of wake-up schedules leading to reduced chances of discovering new nodes in WSN as neighbours. When second category is followed, it may have inefficient slots in the wake-up schedules leading to performance degradation. Therefore, the motivation behind the work in this paper is that by combining the two categories, it is possible to reap benefits of both and get rid of the limitations of the both.

3 Proposed Hybrid Approach to Neighbour Discovery

The current ND approaches that are indirect in nature are categorized into methods of removal of active slots from wake-up schedules and intelligent addition of new slots. The two methods are found to have certain drawbacks. The first category disturbs original integrity of wake-up schedules leading to reduced chances of discovering new nodes in WSN as neighbours. When second category is followed, it may have inefficient slots in the wake-up schedules leading to performance degradation. Therefore, the motivation behind the work in this paper is that by combining the two categories, it is possible to reap benefits of both and get rid of the limitations of the both. Making a hybrid is achieved by introducing virtual nodes that help maximize performance by ensuring original integrity of wake-up schedules and adding of efficient active slots. The proposed protocol named Hybrid Approach to Neighbour Discovery (HAND) is motivated by the facts aforementioned. It overcomes the limitations of existing methods like Extended Quorum System (EQS) that is energy efficient in discovery of neighbours. However, it, in the process of removing active slots, it incorrectly removes them and thus it cannot discover new neighbours efficiently. By using a hybrid approach that considers both intelligent addition and removal of active slots in the wakeup schedules, HAND protocol gains benefits of the two indirect approaches that focus on adding new slots and removal existing slots respectively. The modus operandi of HAND protocol are illustrated in Fig. 1.

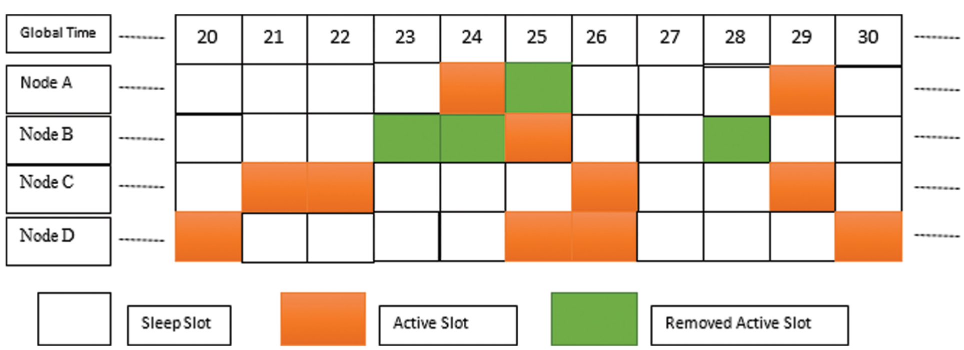

Figure 1: Modus operandi of NAND with Disco as pairwise method

In essence HAND tries to remove active slots that lower energy efficient and ensures discovery of new neighbours. The active slots are arranged in global time from 20 through 30 for different nodes. Based on a distance threshold 20 m, nodes that exhibit smaller distance between them can have more common neighbours. Thus they form a group as discussed in Section 3.1. Such groups are cooperative groups. Assuming that the distance between Node A and B is 15 m, B and C is 25 m and A and C is 30 m. As per the threshold both A and B is a group where node A and B share a task of activating a node using global slots. The HAND follows a hybrid of indirect methods besides using a paired method. In a given cooperative group, the duty cycles are same. Any node's wakeup plan in the given group is the plan of such group. When randomly selected, the active slots for node A are 24 and 29 while slot 25 is the active slot for node B. In slot 25, node A remains in sleep mode while node B is in sleep mode in slots 23, 24 and 28. A removed active slot in the original wake up schedule is considered removed and now it becomes a sleep slot. The node C works as per Disco method. After slot 20, when D is neighbour of A, B, C, in the slot 25 both B and D discover each other. In slot 26, bot C and D discover each other. B broadcasts messages saying that it is very close to A. As per the spatial similarity of neighbours concept D considers A as its neighbour. Thus in summary ND is improved significantly. In case of EQS, the drawback is that D cannot discover other nodes. Therefore, HAND improves the neighbour discovery percentage. In the HAND protocol, the distance between nodes is obtained using RSSI as expressed in Eq. (1).

$$d_{AB} = 10^{\frac{RSSI_{AB} - RSSI_{max}}{10m}} \tag{1}$$

where m denotes path loss exponent while RSSImax denotes the maximum RSSI. The HAND protocol works together with pairwise methods like Disco and Searchlight. Based on distance threshold two nodes can form a cooperative group. Group formation and group cooperation are the two important phases in the proposed protocol. They are computed as in Eq. (2) and Eq. (3) respectively.

$$T_1 = (|log_2(n_{opt})| - 1)t\epsilon + \frac{nopt^{-2|log_2 n_{opt}|}}{2^{|log_2 n_{opt}|-1}}t\epsilon \tag{2}$$

$$T_2 = \frac{d_{TV2} - C_0 - C_1 n - C_2 d_0}{C_3 + C_4 n} \tag{3}$$

The T1 and T2 steps are used in the proposed algorithm below. They are used to determine the respective times such as group formation time and group cooperation time.

The proposed algorithm is meant for achieving better performance with HAND protocol with respect to neighbour discovery.

Algorithm 1: Group Formation and Group Cooperation (GFGC)

```
Initialize group formation time T1
Initialize group cooperation time T2
T1←GetFormationTime() //using Eq. (2)
T2←GetCooperationTime() //using Eq. (3)
For step 1 to 4 of virtual node
 For each pair of two nodes that discover each other
  IF distance <th Then
    Establish a new group
    Nodes of the group can discover neighbours
  End If
  While distance between new group nodes and new neighbour <th Then
    New node is allowed into the group
   End While
  End For
  For nodes in group
```

(Continued)

Algorithm 1: (continued)

```
    IF nodes are in the group Then
      Find valid members
      Share local information
      Re-plan schedules
      Inform end time of cooperating to members
    End If
  End For
  For nodes in the group
    Discover new neighbours
    Share local information
  End For
End For
```

As presented in Algorithm 1, the group formation and group cooperation are controlled in order to have discovery of neighbours based on the HAND protocol. It has number of iterative processes that ensure efficient neighbour discovery. The nodes in the WSN are in a movement model throughout the process. Thus the groups formation is dynamic in nature. Each group where the members are in 20 m range are known as a virtual node. This is the important phenomenon in the HAND protocol. Based on this threshold, the algorithm takes care of making and management of groups. When nodes move away from a group, or when a group is dissolved, the nodes can have their individual wakeup schedules and still wait for an opportunity to form a group for continuous neighbour discovery.

4 Experimental Results

Simulations made using WSN network deployed in 500 × 500 area. The network is divided to form a grid where the side length is 10 m. Nodes are considered to have mobility at the edges of the grid. The slot length considered for simulation is 25 ms to be suitable for the proposed protocol. It is able to reduce collisions and get rid of clock jitters. The experimental results of the proposed method HAND are compared with other ND methods such as EQS (Extended Quorum System), Disco and Searchlight. Observations are made in terms of average discovery latency (slots) and discovered neighbour percentage against duty cycle (%), node density and node speed.

As presented in Fig. 2, the impact of duty cycles is observed on discovered neighbour percentage. The duty cycle (%) is provided in horizontal axis while the vertical axis shows the discovered neighbour percentage. The performance of proposed HAND protocol along with Disco pairwise method in terms of discovered neighbour percentage is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that duty cycles have their impact on the discovered neighbour percentage. As the duty cycles (%) increases, proportionately the discovered neighbour percentage is increased. The HAND + Disco approach outperforms EQS + Disco method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

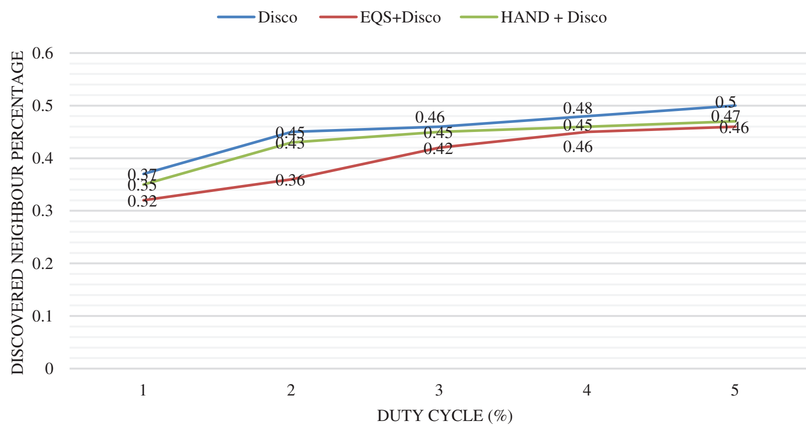

Figure 2: Duty cycle percentage *vs.* discovered neighbour percentage with pairwise method Disco

As presented in Fig. 3, the impact of duty cycles is observed on discovered neighbour percentage with pairwise method as Searchlight. The duty cycle (%) is provided in horizontal axis while the vertical axis shows the discovered neighbour percentage. The performance of proposed HAND protocol along with Searchlight pairwise method in terms of discovered neighbour percentage is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that duty cycles have their impact on the discovered neighbour percentage. As the duty cycles (%) increases, proportionately the discovered neighbour percentage is increased. The HAND + Searchlight approach outperforms EQS + Searchlight method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

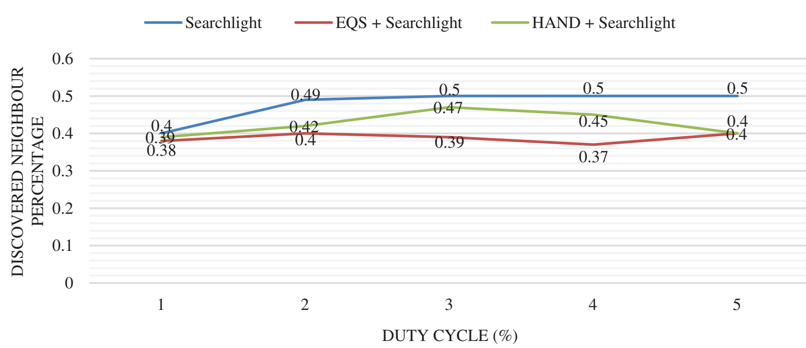

Figure 3: Duty cycle percentage *vs.* discovered neighbour percentage with pairwise method Searchlight

As presented in Fig. 4, the impact of node density is observed on average discovery latency (slots). With pairwise method as Disco. The node density is provided in horizontal axis while the vertical axis shows the average discovery latency (slots). The performance of proposed HAND protocol along with Disco pairwise method in terms of average discovery latency (slots) is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that node density have their impact on the average discovery latency (slots). As the node density increases, the average discovery latency (slots) is slightly changed. The HAND + Disco approach outperforms the Disco and EQS + Disco methods due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

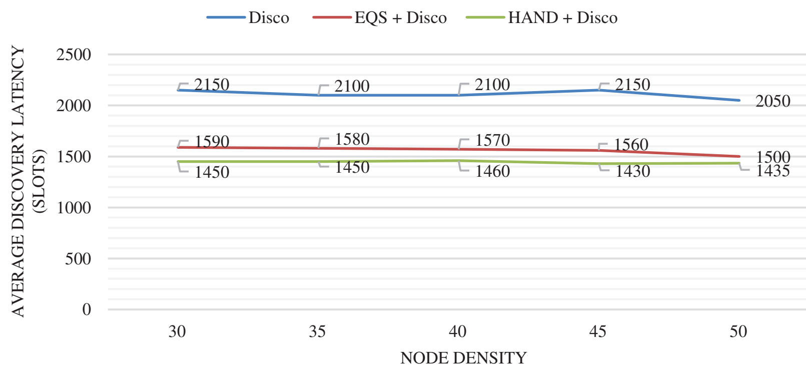

Figure 4: Node density *vs.* average discovery latency (slots) with Disco as pairwise method

As presented in Fig. 5, the impact of node density is observed on discovered neighbour percentage with pairwise method as Disco. The node density is provided in horizontal axis while the vertical axis shows the discovered neighbour percentage. The performance of proposed HAND protocol along with Disco pairwise method in terms of discovered neighbour percentage is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that node density have its impact on the discovered neighbour percentage slightly. As the node density increases, the discovered neighbour percentage is slightly changed. The HAND + Disco approach outperforms EQS + Disco method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

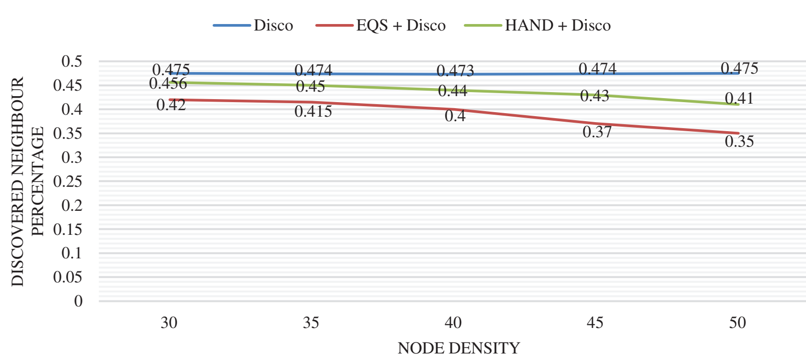

Figure 5: Node density *vs.* discovered neighbour percentage with Disco as pairwise method

As presented in Fig. 6, the impact of node density is observed on average discovery latency (slots) with pairwise method as Searchlight. The node density is provided in horizontal axis while the vertical axis shows the average discovery latency (slots). The performance of proposed HAND protocol along with Searchlight pairwise method in terms of average discovery latency (slots) is compared against state of the art methods such as Searchlight and EQS + Searchlight methods. An important observation is that node density have its impact on the average discovery latency (slots). As the node density increases, the average discovery latency (slots) is significantly changed. The HAND + Searchlight approach outperforms EQS + Searchlight method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

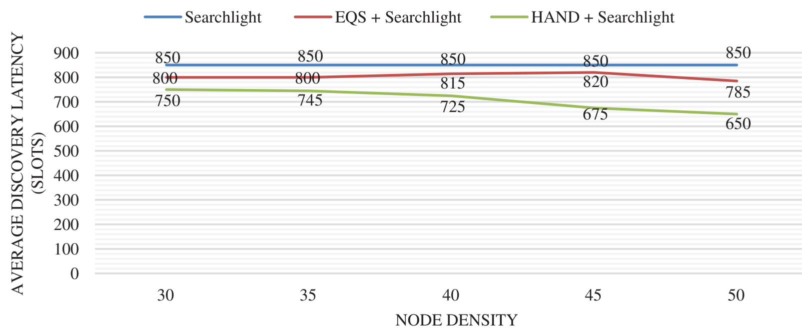

Figure 6: Node density *vs.* average discovery latency (slots) with Searchlight as pairwise method

As presented in Fig. 7, the impact of node density is observed on neighbour discovery percentage with pairwise method as Searchlight. The node density is provided in horizontal axis while the vertical axis shows the neighbour discovery percentage. The performance of proposed HAND protocol along with Disco pairwise method in terms of neighbour discovery percentage is compared against state of the art methods such as Searchlight and EQS + Searchlight methods. An important observation is that node density have its impact on the average discovery latency (slots). As the node density increases, the neighbour discovery percentage is significantly changed. The HAND + Searchlight approach outperforms EQS + Searchlight method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

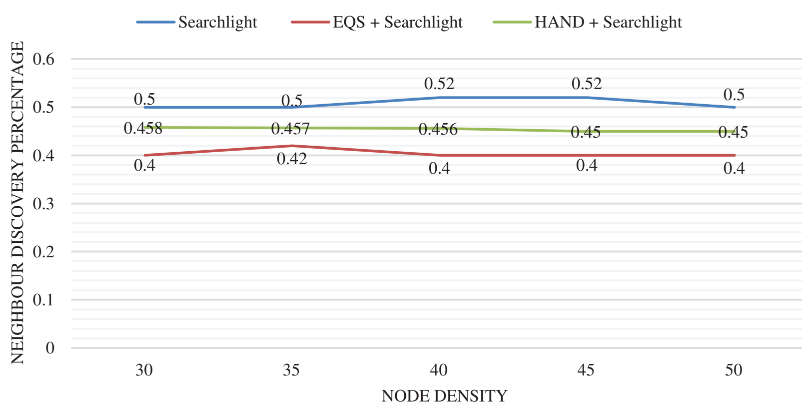

Figure 7: Node density *vs.* neighbour discovery percentage with Searchlight as pairwise method

As presented in Fig. 8, the impact of node speed is observed on average discovery latency (slots) with pairwise method as Disco. The node speed is provided in horizontal axis while the vertical axis shows the average discovery latency (slots). The performance of proposed HAND protocol along with Disco pairwise method in terms of average discovery latency (slots) is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that node speed has its impact on the average discovery latency (slots). As the node speed increases, the average discovery latency (slots) is significantly changed. The HAND + Disco approach outperforms Disco and EQS + Disco methods due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

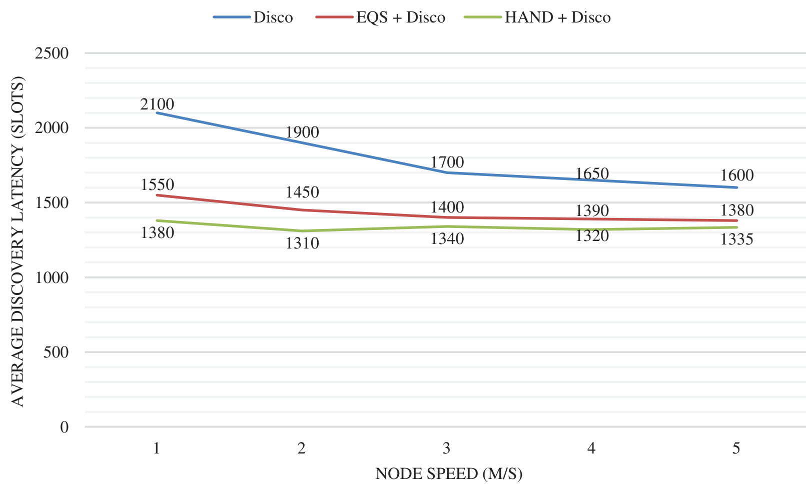

Figure 8: Node speed *vs.* average discovery latency (slots) with Disco as pairwise method

As presented in Fig. 9, the impact of node speed is observed on discovered neighbour percentage with pairwise method as Disco. The node speed is provided in horizontal axis while the vertical axis shows the discovered neighbour percentage. The performance of proposed HAND protocol along with Disco pairwise method in terms of discovered neighbour percentage is compared against state of the art methods such as Disco and EQS + Disco methods. An important observation is that node speed has its impact on the discovered neighbour percentage. As the node speed increases, the discovered neighbour percentage is significantly changed. The HAND + Disco approach outperforms EQS + Disco method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

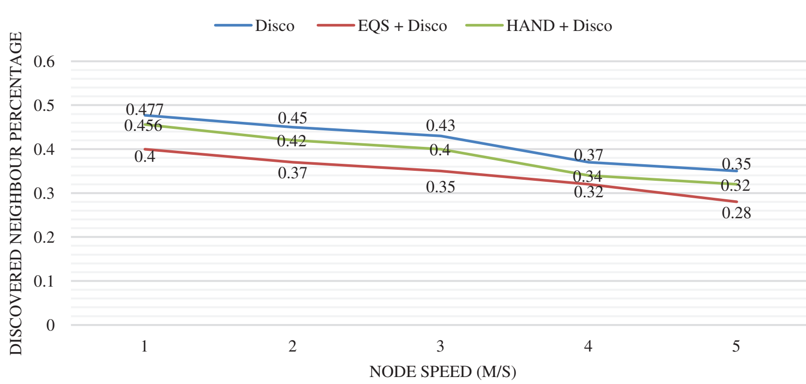

Figure 9: Node speed *vs.* discovered neighbour percentage with Disco as pairwise method

As presented in Fig. 10, the impact of node speed is observed on average discovery latency (slots) with pairwise method as Searchlight. The node speed is provided in horizontal axis while the vertical axis shows the average discovery latency (slots). The performance of proposed HAND protocol along with Searchlight pairwise method in terms of average discovery latency (slots) is compared against state of the art methods such as Searchlight and EQS + Searchlight methods. An important observation is that node speed has its impact on the average discovery latency (slots). As the node speed increases, the average discovery latency (slots) is significantly changed. The HAND + Searchlight approach outperforms Searchlight and EQS + Searchlight methods due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

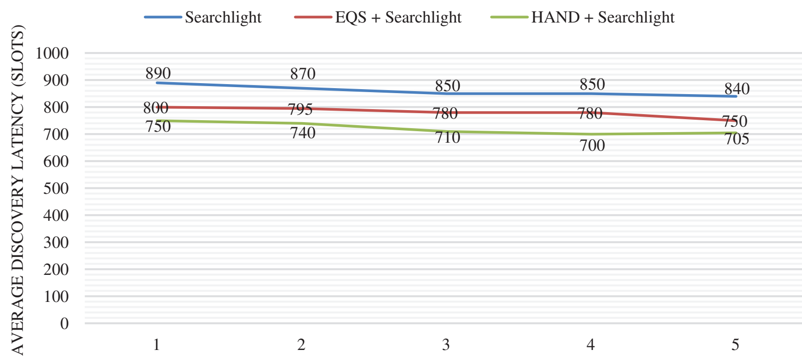

Figure 10: Node speed *vs.* average discovery latency (slots) with Searchlight as pairwise method

As presented in Fig. 11, the impact of node speed is observed on discovered neighbour percentage with pairwise method as Searchlight. The node speed is provided in horizontal axis while the vertical axis shows the discovered neighbour percentage. The performance of proposed HAND protocol along with Searchlight pairwise method in terms of discovered neighbour percentage is compared against state of the art methods such as Searchlight and EQS + Searchlight methods. An important observation is that node speed has its impact on the discovered neighbour percentage. As the node speed increases, the discovered neighbour percentage is significantly changed. The HAND + Searchlight approach outperforms EQS + Searchlight method due to its strategy in usage of discovery schedules efficiently besides maintaining integrity of wakeup schedules of nodes.

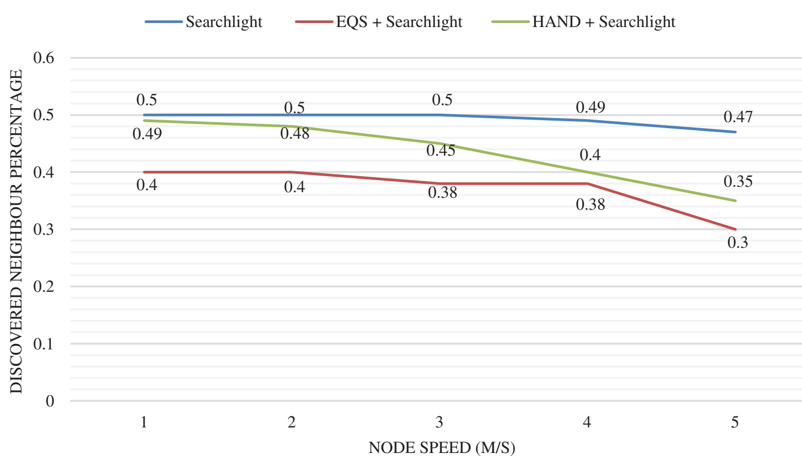

Figure 11: Node speed *vs.* discovered neighbour percentage with Searchlight as pairwise method

5 Conclusion and Future Work

In this paper a hybrid ND protocol is proposed that combines feature of two categories of ND to reap benefits of both and get rid of the limitations of the both. The current ND approaches that are indirect in nature are categorized into methods of removal of active slots from wake-up schedules and intelligent addition of new slots. The two methods are found to have certain drawbacks. The first category disturbs original integrity of wake-up schedules leading to reduced chances of discovering new nodes in WSN as neighbours. When second category is followed, it may have inefficient slots in the wake-up schedules leading to performance degradation. Making a hybrid is achieved by introducing virtual nodes that help maximize performance by ensuring original integrity of wake-up schedules and adding of efficient active slots. Thus a Hybrid Approach to Neighbour Discovery (HAND) protocol is realized in WSN. The simulation study revealed that HAND outperforms the existing indirect ND models. In future, we intend to improve our protocol by using information of discovered neighbours and re-plan ND leading to minimize latency and improve energy efficiency further.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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