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Energy adaptive block design based neighbor discovery for asynchronous wireless sensor networks

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Abstract

Background: The need for an efficient neighbor discovery model is tremendously essential with the development of Wireless Sensor Networks (WSNs). The neighbor discovery model has growingly been significant in enhancing the performance of WSNs. **Methods**: In this study, adaptive energy duty-cycle, energy-efficient Balanced Incomplete Block Design (BIBD) hybrid scheme is proposed for WSNs that controls collisions, and overhearing obstacle by maintaining energy over WSNs. Energy adaptive BIBD leverages the features of symmetric BIBD. Evaluation of the proposed model is demonstrated using the TOSSIM tool, and the performance parameters are compared with other well-known neighbor discovery process, including Disco, U-Connect, and Searchlight, Hedis, and Todis algorithms. **Findings**: The outputs of our simulation study illustrates that the proposed model significantly outperforms other neighbor discovery algorithms with reference to energy-efficiency and discovery latency.

Keywords: Wireless sensor networks; energy efficiency; neighbor discovery; block design; collisions

1 INTRODUCTION

In the last decade, the use of Wireless Sensor Networks (WSNs) are increased in many fields such as long-term environmental monitoring, tracking objects, military applications, and so on [1]. In general, WSNs composed of hundreds and thousands of tiny sensor nodes which can gather various physical data from their surroundings. These resource-constrained limited battery power, low cost, limited processor capacity tiny sensor nodes are deployed in obstacle areas. Then, obtained physical data transferred to the base station through multi-hop communication or directly. Sensor nodes not only collect physical data from their surroundings but also act as routers [2]. Due to their resource constraints, and they sustained until sensor nodes energy drains. The paramount objective of WSN applications is to enlarging the lifespan of sensor nodes by reducing energy consumption [3,4].

A careful design of neighbor discovery algorithms and protocols for energy-efficient communication has become one of the essential issues in WSNs to enlarging sensor nodes lifespan [5]. Therefore, the neighbor discovery protocols must be energy efficient and must try to minimize the energy consumption in various areas such as overhearing, data collection, idle listening, control packet overhead, and over-emitting. With efficient neighbor discovery protocols, sensor nodes might save a lot of energy to establish a communication path with others [6,7].

The basic idea behind the neighbor discovery process is to split the time used by sensor nodes over channel access into equal-length time slots, and every node can use one exclusively by one node [7]. Therefore, applying a neighbor discovery mechanism, every node requires to choose one schedule which contains a sequence of ON and OFF in advance. Where ON indicates active mode node turns on by its radio and OFF represents sleep mode, node turns off by its radio. Here, a schedule designed based on Balanced Incomplete Block Design (BIBD) initially introduced in [8]. The fundamental goal of the implemented protocol is to minimize the overall energy consumption by using BIBD symmetric neighbor discovery schedule. In order to reduce energy consumption, the primary function is to schedule the sensor nodes with various radio modes such as active and sleep in consecutive time slots. The minimization of energy consumption can be achieved because sensor devices use different levels of energy at each node [9].

The neighbor discovery process based on BIBD provides or optimal solution in terms of the average case discovery latency of the desired duty cycle. In WSNs, applications are obtaining neighbor nodes information based on BIBD applicable to symmetric strategies. To make BIBD based neighbor discover appropriate to asymmetric environment, the prime number based BIBD developed to design efficient neighbor discovery algorithms. In many WSN applications are desired to work for several months to years without any human intervention. However, resource-constrained sensor nodes in a sensor network may discontinue their operations due to the energy of the node drained out. Therefore, endorsing the lifespan of the network is essential for sensor network functionality.

The neighbor discovery is not one time process, due to the deployment of new nodes, collisions, topology changes, and clock synchronization among nodes need to discover neighbors continuously. In this paper, we propose an energy adaptive-BIBD based neighbor algorithm that adopts both symmetric and asymmetric strategies. The significant contribution in this paper as follows.

This study is the first of its kind to design neighbor discovery by considering the remaining energy of node to construct BIBD based neighbor discovery schedule where they must guarantee the existence of overlapping active slots between any two sensor nodes.

In this work, it is implemented some representative models of the neighbor discovery process in TOSSIM simulation [10]. The outputs of our simulation study illustrates that the proposed model significantly over other neighbor discovery algorithms according to energy-efficiency and discovery latency.

There is a vast literature on neighbor discovery algorithms in WSNs and Ad-Hoc networks. Then, this study uses and divides the existing neighbor discover algorithms into the three important modules, such as BIBD-based, Prime number, and Quorum based. The various simulation tools used by researchers to describe models are presented in Table 1.

Table 1. Various simulation tools used by researchers

Protocol Category	Author	Description, advantages, and disadvantages/ future directions
Quorum-based Protocol	Jiang et al. [11]	• Quorum based neighbor discovery derived from an $n \times n$ matrix. • It selects one row and one column form the proposed matrix, and assign them to a node discovery schedule. • The chosen column and row then act as active states of a node, and the remaining slots are sleep slots. • Simple model for implementation. • Higher efficient. • Typically, the original Quorum based neighbor discovery protocols are not suitable for asymmetric approaches.
	Bakht et al. [12]	• To reduce the problem of the basic Quorum based approach by considering the halve of the Quorum based discovery schedule called searchlight. • It can support both symmetric and asymmetric approaches. • Searchlight has shorter discovery latency and minimum energy consumption because of the half discovery schedule length. • Not suitable for heterogeneous environments

Continued on next page

Table 1 continued

	Chen et al.[13]	• The proposed model called Hedis and Todis to reduce the problem fundamental matrix-based neighbor discovery similar to searchlight. • Simple model for implementation • Low error rate • It can be implemented in both homogeneous and heterogeneous environments. • It needs more slots, compromises energy efficiency and latency.
Balanced Incomplete Block Design (BIBD) based protocols	Zheng et al.[14]	• The proposed model used a combinatorial structure for block design. • BIBD that designs a sensor device discovery schedule through the block design. • The simulation results of BIBD based neighbor discovery produces an optimal solution. • It is designed for symmetric networks, where sensor nodes have a homogeneous discovery schedule.
	Lee et al.[15]	• To address the problem of symmetric discovery schedule proposed in symmetric-BIBD, combining duty cycle schedules by using OR operation to make it applicable for asymmetric discovery schedule. • Which requires additional active slots • Significantly increases energy consumption.
	Lee et al.[16]	• Proposed model Combining duty cycle schedules by using XOR operation. • It also uses additional active slots to address the symmetric discovery schedule. • Increases energy consumption.
	Lee et al.[17]	• It supports both symmetric and asymmetric strategies. • It removes additional active slots whenever possible in most of the environments. • The proposed model uses the basic BIBD without additional active slots. • It improved energy efficiency and reduced worst-case latency. • Not effective in route discovery when BIBD blocks are not available for certain duty cycles.
Prime number based protocols	Ding et al.[18]	• Chinese Remainder Theorem (CRT) used for cryptography applications and success of this approach worked for constructing discovery schedules for both symmetric and asymmetric strategies in WSNs.
	Dutta et al.[19]	• The proposed protocol is called Disco. Each sensor randomly selects one prime number to construct a discovery schedule. • When two sensor nodes select distinctly prime numbers, if the selected prime numbers are relatively prime, then it guarantees the existence of common active slots between any two nearby nodes. • Improved energy efficiency and latency • Worst-case latency is still high.
	Kandhalu et al.[20]	• It uses a single prime number to construct a neighbor discovery schedule. • It adds periodic active slots based on the prime number. • Worst-case latency is still high.

2 BIBD and neighbor discovery problem

This section is focused on how the BIBD blocks are useful for constructing neighbor discovery in wireless sensor networks, and introduces the node energy estimation for creating neighbor discovery[21]. The neighbor discovery in WSN can play a vital role in relaying sensed information from source node to sink node through multi-hop communication. Block designs have many mathematical contexts used in variant fields such as geometry, networking, software testing, and cryptography. Among the block designs, the BIBDs are most suitable for the neighbor discovery algorithm due to their structural properties shown below. Next, we give two definitions of combinatorial block designs [22], and then we define relation with wireless sensor networks.

Definition 1: A design is a pair $(X,\ A)$satisfying the following properties.
a) X is a set of elements, called points and
b) A is a collection (i.e., multiset) of nonempty subsets of X, called blocks.
Balanced Incomplete Block Design is a well-structured optimal block design for many WSN applications [8].

Definition 2: Let $v,\ k,\ and\ \lambda$ be positive integers such that $v > k \geq 2$. A $(v,\ k,\ \lambda)$ – BIBD is a design $(X,\ \ A)$ that satisfies the following properties.
a) $(X| = v$.
b) Each block contains exactly k-points.
c) Every pair of distinct points is contained in exactly λ blocks.
For illustration, assume that the set X is $(1,\ 2,\ 3,\ 4,\ 5,6,\ 7,\ 8,\ 9\}$ and the multiset A contains $\{123, 456, 789, 147, 258, 369, 159, 267, 348, 168, 249, 357\}$, that described structure $(X,\ A)$satisfies the three features of definition 2. Specifically $(X,\ \ A)$ is a $(9,3,1)-$BIBD, and it is not unique. For instance, the multiset A contains $\{124,\ 235, 346, 457, 568, 679, 136, 257, 379, 248, 689\}$, there $\left(X, A'\right)$ and also satisfies the three properties of basic BIBD structure described in definition 2 [14].

Most of the applications composed of hundreds or thousands of sensor nodes, and these nodes can switch between active and sleep to prolong the lifespan of a node. The neighbor discovery is essential to relay data origin to processing node through wireless multi-hop communication. We use a pattern of 0 and 1 to indicate a discovery schedule. Where 1 equates to the active slot of a node when it turns on by radio, and 0 shows the sleep slot when node turns off by radio. The sensor neighbor discovery schedules are denoted with a pattern of binary number.

Definition 3: Let assume the ubiquitous set X as $(1,2,3,4,5,\ldots,v\}$, and let a block be a nonempty subset of X. A block-based schedule of a node k is defined as a pattern of binary number [15].

$$S_m^v = \begin{cases} \langle x_i\rangle_{i=1}^{v} \text{ such that } x_i = 1 \ \text{ if } i \in A \ (\mod v) \\ 0 \ \ otherwise \end{cases}$$

For instance, we use $(369\}$ block in the $(9,3,1)-$BIBD. If a sensor node uses a block, A for scheduling node turns on by radio to transmit or receive the data packets beginning of slots. Figure 1 illustrates the node active and sleep patterns in a schedule of a sensor node uses the $(369\}$ block in the $(9,3,1)-$BIBD.

Time slot	1	2	3	4	5	6	7	8	9
$Nodem_i$(3,6,9)	0	0	1	0	0	1	0	0	1
	Sleep	**Sleep**	**Active**	**Sleep**	**Sleep**	**Active**	**Sleep**	**Sleep**	**Active**

Fig 1. Example of a node active and sleep based on BIBD

Definition 4: The percentage of active slots and the total number of slots (i.e., active and sleep time slots) in a node schedule is called the duty cycle of the node. If BIBD schedule $S_m^v$of a sensor m as schedule $S_m^v = \langle x_1, x_2, x_3, \ldots, x_v\rangle$, then the duty cycle of node m denoted as follows:

$$DC_m = \frac{A}{T} \times 100$$

Where $A = \sum_{i=1}^{v} x_i$ indicates the sum of the active slots of discovery schedule, and T is total slots in a schedule for a $(9,3,1)-$BIBD. For instance, the duty cycle schedule of a node m_i uses the $(369\}$ block in the $(9,3,1)-$BIBD, as shown in Figure 1, which is expressed as follows:$DC_m = \frac{3}{9} \times 100$ = 33%. Lack of global synchronization among nodes due to uneven clock drift of sensor nodes in WSN turns on by radio in irregular intervals or time slots. In sensor networks, node discovery schedules do not start at the same time because nodes may have independent duty cycles. For instance, if the BIBD based schedule of sensor node m_i, begins at a random slot $c > 0$ (called as clock drift). The schedule of a node m_i is given as follows:

$$S_m^v = \begin{cases} 1 & \langle x_i + c\rangle_{i=1}^{v}, \text{ such that } x_i = 1 \text{ if } i - c \in A(\mod v) \\ 0 & \text{otherwise} \end{cases}$$

In a single-channel wireless multi-hop communication neighbor discovery is a challenging task due to channel interference, data collisions, and radio interferences. Therefore, sensor nodes may not be able to find any other nodes within their schedule active slots. Sensor node should be repeated discovery schedule and adjust duty cycle length according to the remaining energy. The entire process of WSN broadly classified into three phases, such as deployment, discovery, and communication. After deployment, sensor nodes in the network autonomously obtain nearby node information using the discovery schedule of a node S_m. The schedule length of any two nodes may or may be equal if the duty cycle of any two neighbor nodes is different, that two nodes not have any common active slots assigned duty cycles. The sensor nodes switch the radio between on and off throughout the schedule. Therefore, a node can find the existence of other nodes, if they have common active slots. Otherwise, they will not discover each other during the operation time. Two make efficient asynchronous neighbor discovery were used to perform $\otimes$ operator between any two discovery schedules $S_{m_i}^v, S_{m_j}^v$ then resultant schedule for neighbor discovery as follows $S_{m_i}^{v_i} \otimes s_{m_j}^{v_j} = \langle x_i \times y_j \rangle_{i=1}^{L}$. Where x_i *and* x_j are pattern of $S_{m_i}^v$, $S_{m_j}^v$, $L = LCM\,(v_i, v_j)$. Therefore, $\sum_{i=1}^{L} = \ x_i y_i$ denotes the number of common active slots between two nodes m_i and m_j within the length L.

The Balanced Incomplete Block Design (BIBD) based neighbor discovery techniques an optimal solution for WSNs with symmetric and asymmetric duty cycles [15]. For instance, we assume a sensor network environment initially does not know about neighbor discovery schedules. Then any two nearby nodes have different duty cycles at the beginning of network initialization. Assume any sensor nodes such as m_i and m_j have independent duty cycles, where there is no common active slots. Figure 2 illustrates the duty cycle of two sensor nodes m_i and m_j. The sensor node

Slot No:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(1,4,7)	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
(3,5,11,14,17)	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0

Figure 2. The discovery schedule of two nodes not have common active slots

Fig 2. The discovery schedule of two nodes not have common active slots

m_i uses the $(1,4,7\}$ block in the $(9,\,3,\,1) - BIBD$that is $S_{m_i}^9 = \langle 1,0,0,1,0,0,1,0,0\rangle$. The sensor node m_j uses the$(3,\,5,11,14,17\}$ block in the $(21,5,1) - BIBD$that is$S_{m_2}^{21} = \langle 0,0,1,0,1,0,0,0,0,0,1,0,0,1,0,0,1,0,0,0,0\rangle$. These sequences of 0s and 1s repeats up to a certain amount of residual energy of node. There are no common active patterns between $S_{m_1}^9$ and$S_{m_2}^{21}$. Therefore, sensor nodes m_1 and $m_2$in asynchronous wireless network will never discover each other. In order to handle this situation, we use the prime number based asymmetric BIBD neighbor discovery schedule for asynchronous wireless sensor networks that efficiently coordinate to enlarge active slots between nodes. Initially, it constructs a discovery schedule with the help of BIBD neighbor discovery for a chosen duty cycle. However, the lengths of two discovery schedules of two desired duty cycles decide the difficulty of supplementary active slots.

Let S_{m_1} and S_{m_2} are two discovery schedules of sensor nodes $m_1$and m_2, and their associated lengths are L_{m_1} and L_{m_2}. If GCD of sensor nodes discovery schedule S_{m_1} and S_{m_2} is 1 (i.e., $GCD\,(S_{m_1},\,S_{m_2}) = 1$), they constructed a discovery schedule of two duty cycles that have guarantee common active slots and doesn't require any supplementary active slots. Otherwise, $GCD\,(S_{m_1},\,S_{m_2}) \neq 1$), then discovery schedules of a two sensor nodes duty cycles require extra active slots. To unravel the problem of asymmetric block design, we use the extended block design schedule. Then we select a prime number that satisfying $p = min\,((v-p| : p \in P,\ p \leq v\}$, where P is the set of prime numbers.

The extended block design based on the selected prime number and that is, $(x_1, x_2, x_3, \ldots, x_n\} \cup (p\}$. Then sensor node extended block design discovery schedule is defined as follows

$$S_{m_i}^{vp} = \begin{cases} 1 & \langle x_i \rangle_{i=1}^{vp}, \text{ such that } x_i = 1 \text{ if } i \in A \ (\mod v) \\ 0 & otherwise \end{cases}$$

For instance, The sensor node m_i uses the $(1,4,7\}$ block in the $(9,\ 3,\ 1) - BIBD$, and sensor node m_j uses the $(3,\ 5, 11, 14, 17\}$ block in the $(21, 5, 1) - BIBD$. Therefore, $GCD\,(9, 21) = 3$, prim-based discovery schedule adds extra active slots.

Figure 3 illustrates that the representation asymmetric neighbor discovery schedule. Here, the greatest prime number below 21 is 19, then extended block design for sensor node $m_2$discovery schedule is $\{3,\ 5,\ 11,\ 14,\ 17\} \cup \{19\}$. Therefore, by using the Chinese Remainder Theorem, the two sensor nodes m_1 and m_2 have a common active slot at indexes 19, 40, 61, and more.

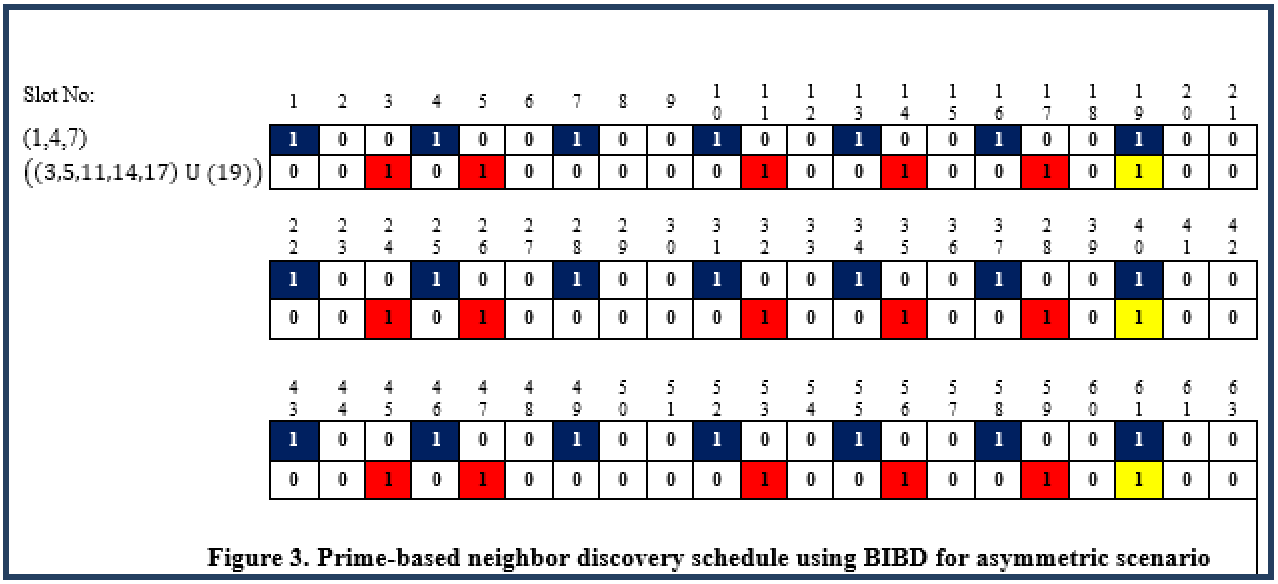

Fig 3. Prime-based neighbor discovery schedule using BIBD for asymmetric scenario

Most of the energy consumption can occur during communication among nodes in the network. The network lifespan can be enlarging long enough to fulfill the application requirement by adapting the minimum energy consumption mechanisms[12]. It also crucial for the allocation of a communication channel among nodes; the proposed model satisfies some of the critical factors such as energy-efficiency, collision, and minimum latency in sensor networks. Sensor nodes in networks alternate between active and sleep modes to use on the network activity and requirement[13]. The energy consumption problem can be appended due to the number of awake slots in a schedule, and there is a trade-off between the duty cycle and delay. If the number of active slots in schedule increases, then the discovery delay is minimized and vice-versa. The existing symmetric and asymmetric BIBD based neighbor discovery can achieve by constructing a fixed duty cycle schedule over the network lifespan. The adaption of schedule based on the residual energy of node status is beneficial in designing the duty cycle schedule. Lee and Kin proposed a model dynamic phase shift, and Zhang et al.[14]Implemented a novel scheduling scheme called traffic adaptive duty cycle strategies for minimizing the energy consumption. These implemented can also avoid the collisions and delay in asynchronous WSNs.

3 Neighbor discovery schedule based on residual energy

Wireless Sensor Networks has a broad range of applications over many fields. WSNs are composed of hundreds or thousands of low cost and tiny sensor nodes and these sensor nodes are mostly battery-powered devices. Sensor nodes deployed for gathering helpful or needed information and transmit them via wireless communication paths from the physical area to the sink node or base station. Once these sensors deployed in unattended area replacement or recharging batteries impossible or a critical task. The communication of these sensor nodes happen either within themselves or else directly with the sink node. Energy efficiency has become a critical issue in WSNs. Therefore, the resource selection and communication need to optimize to enlarge the lifespan of the network. Figure 4 illustrates the proposed neighbor discovery process for

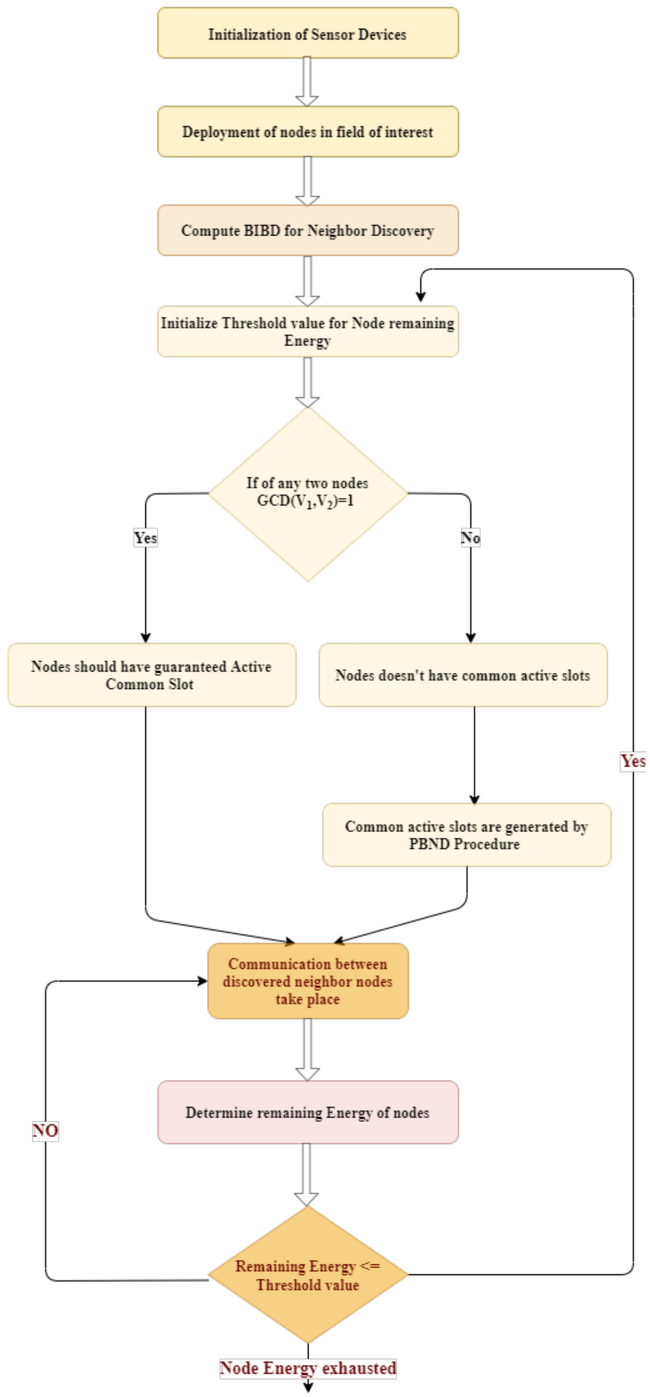

Fig 4. Flowchart for proposed Neighbor Discovery process in Asynchronous WSN

asynchronous wireless sensor networks. The neighbor discovery process, according to the residual energy, is affecting the sleep latency to balance energy conservation between sensor nodes. Discovery latency described as a sensor node that has data to receive or transmit typically needs to wait for a long duration before actual transmitting or to get the data packet[23]. Generally, minimum discovery latency reduces energy utilization. Therefore, it significantly is enlarging the lifespan of a sensor node in the networks. Our proposed model allows every node to construct the discovery schedule based on the residual energy of a node after every neighbor discovery. Following algorithm illustrates proposed block design based neighbor discovery for asynchronous wireless sensor networks

Algorithm: Implementation of Block Design based Neighbor Discovery for Asynchronous WSNs
1. Initialize the list of nodes
2. Initialize the E_{rem}, $E_{tr/re}$, λ, and E_{th} Threshold
3. Procedure to design_Block() //Compute Balanced Incomplete Block Design (BIBD) based schedule
4. For k ε [1, # ListNodes] do
5. For j ε [1, # ListNodes] do
6. If(gcd(V_k,V_j) == 1) then
7. k and j are neighbors have common active slot
8. Else
Compute new block Prime based schedules for these nodes with common active slot
9. End if
10. $E_{rem} = E_{rem} - E_{tr/re}$ // to compute remaining energy of nodes
11. If ($E_{rem} \leq E_{th}$ and E_{rem} != 0) then
12. design_Block() //nodes need to adjust duty cycle length according to node remaining energy

To determine the schedule, we consider the discovery duty cycle schedule and residual energy of each node. Let assume a node denotes m_i and its residual energy represented as E_{re}. The relation among these can be defined as follows:

$$DC_{m_i} \propto \frac{1}{E_{re}^{m_i}}$$

Suppose after deployment, each node has maximum energy E_{max}, and then the sensor can produce a minimum delay BIBD based on neighbor discovery duty cycle schedule. Let assume $DC^{max}$is an initial duty cycle, and E_{max} denotes the original energy of the sensor. After a certain number of sequence of transmitting or receiving operations, each node spent some amount of energy to perform various functions. If residual energy of a sensor m_i less than the dynamic threshold value E_{th}, then BIBD based neighbor discovery duty cycle can be constructed to enlarging the lifespan of the network.

$$E_{re}^{m_i} = E_{re}^{m_i} - E_{tr}^{m_i}$$

Where $E_{tr}^{m_i}$ denotes energy used for transmitting or receiving data packet of a sensor m_i. Let assume the maximum duty cycle of a node represented as $DC_{m_i}^{max}$. If residual energy is less than the defined threshold value, then a new duty cycle schedule constructed as calculated as follows:

$$DC_{m_i}^{max} = DC_{m_i}^{max} - \left(DC_{m_i}^{max} * \left(\frac{E_{re}^{m_i} - E_{th}}{E_{max}^{m_i} - E_{th}} \right) \right)$$

Where E_{max} is used in representing the maximum energy or new energy of a sensor, whenever a new BIBD based discovery schedule is constructed, then E_{th} also generated based on the remaining power of a node in sensor networks.

4 Performance analysis and evaluation

In this section, we analyze and evaluate the performance of discovery latency and energy consumption of the proposed model based on energy adaptive neighbor discovery using BIBD. We compare with existing protocols such as Disco, Searchlight, U-Connect, Hedis, and Todis in both symmetric and asymmetric approaches using a simulation tool. The primary goal of the simulation is to handle the practical applications consuming less energy with efficient and faster data delivery. To evaluate the efficiency of the proposed neighbor discovery scheme, we have implemented the proposed model and other earlier neighbor discovery model by using a TOSSIM module [10]. The same parameters have been used for all neighbor discovery protocols for simulation.

For the proposed scheme, the simulation approach contains 150 nodes with a transmission range of 50m. The sensor devices are randomly deployed uniformly on the filed of environment of 500 × 500 square meters. The maximum energy or initial energy of a node is 3.7J, and the maximum energy consumption for each sensor device is set to 16mW. Each sensor device alternates between active and sleep states and capable of broadcasting the data at power intensity ranging from -20dBm to 12dBm. Table 2 shows that simulation parameters assumed to analyze the proposed model with other previously defined well-known models.

Table 2. Summarized simulation parameters for the proposed energy adaptive neighbor discovery model based on BIBD

Name of the parameter	Values
Size of the networks	500×500
Number of sensor nodes	150
Sensing ranging of nodes	$30m$
Initial energy of node	$3.7J$
Network Topology	Random topology
Channel Access Scheme	CSMA/CA
Simulation time	$45m$
Initial trigger time	$50s$
Transmission energy	$16mW$
Receive energy	$12mW$
Packet transmission rate	$40\ packets/s$
Type of protocol	Hybrid model
Power intensity	$-20dBmto\ 12dBm$
Neighbor discover protocols	Disco, Searchlight, U-Connect, Hedis and Todis

For the evaluation and comparison of asymmetric duty cycles, the asymmetric ratio R is defined as DC_h/DC_l where DC_h indicates the duty cycle of higher duty cycle and DC_l represent the duty cycle of the lower duty cycle. For instance, if one block of sensor nodes have 10% and other blocks of sensor node have 2%, then $R = \frac{10}{2}\% = 5\%$. The evaluation outputs are shown in Figures 4 and 5. In general, if symmetric ratio increases the energy consumption of nodes in the proposed scheme significantly smaller than other existing neighbor discovery protocols, because of the delay for the lower duty cycle neighbor enhanced and importantly due to the increased length of the discovery schedule and also based on the remaining energy of the node.

The lifespan of the sensor network is determined by the overall power conservation of sensor devices. The power conservation of sensor devices increases the lifespan of these devices is decreased, and vice-versa. To simulate the impact of the discovery duty cycles on the discovery latency during asymmetric operations, we used different pairs of discovery duty cycles such as $((10\%,1\%),(10\%,2\%),(10\%,5\%),(10\%,10\%))$. Figure 5 illustrates the relation between power consumption and the ratio of duty cycles compared with other protocols for the neighbor discovery. It is concluded from the evaluation outputs that duty cycles defined in the above pairs.

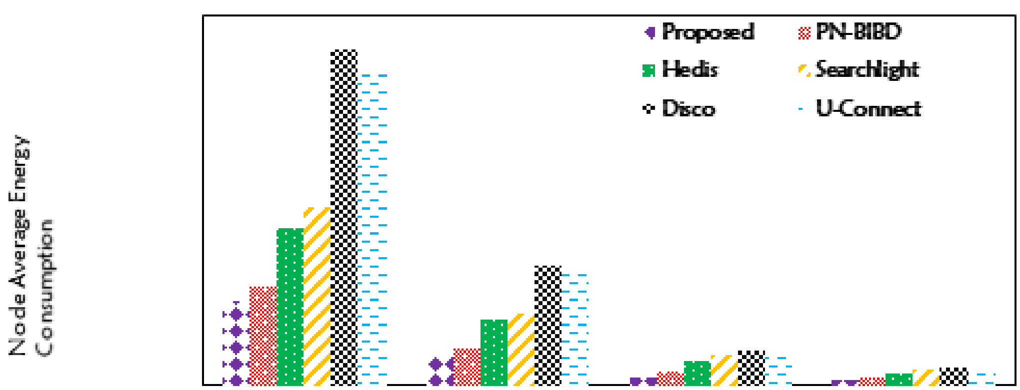

Fig 5. Sensor node average energy consumption

The energy conservation by the sensor nodes decreases curvy linearly, and for duty cycle below $(2\%, 1\%)$the energy consumption by the sensor nodes increases linearly.

Figure 6 shows that the proposed scheme extremely outperforms all well-known neighbor discovery protocols in terms of energy utilization, and also illustrates the lifespan of the sensor devices and discovery ratio of duty cycles. It is concluded that the evaluation results of discovery ratio duty cycles decrease the lifespan of sensor devices increases significantly. Therefore, the lifespan of the proposed model significantly more abundant than other models.

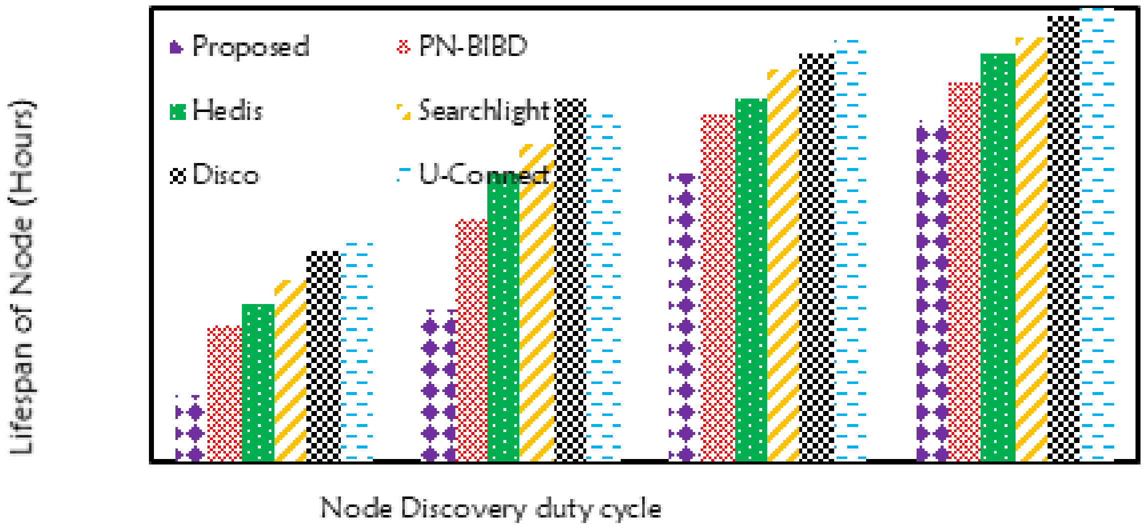

Fig 6. Relation between lifespan of a node and duty cycle in asymmetric asynchronous wireless sensor networks

5 Conclusion

This study introduces a new energy adaptive neighbor discovery protocol based symmetric BIBD for symmetric and asymmetric asynchronous wireless sensor networks. In this proposed model, the features of symmetric and BIBD and Chinese Remainder Theorem are merged to design schemes for asymmetric discovery duty cycles. The major contribution of the proposed system to develop an efficient dynamic duty cycle schedule based on the residual energy of a sensor. Therefore, the proposed strategy anticipates an efficient solution for asymmetric and symmetric discovery schedule problems. As per simulations a result, the performance of the proposed model is significantly smaller energy compared to the other well-defined neighbor discovery protocols, and it can be enlarging the lifespan of the network compared with well-defined protocols.

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