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A survey on continuous neighbor discovery for mobile low duty cycle wireless sensor network

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ABSTRACT

In the network implementation point, neighbourhood exploration is a very significant phenomenon. However, due to the complex existence of WSN and the probability of adding new nodes and withdrawing nodes from the network, continuous exploration of neighbours is required. It does suggest that the identification of neighbours is not a one-time operation. There are also benefits of WSN for the identification of neighbours. In addition to saving node power and growing node life, network reliability is increased. The analysis of the literature in this paper gives valuable insights into the latest state of the art in continuous exploration of neighbours in WSN. In specific, it reflects on the WSNs of the low duty mobile cycle. The analysis holes found in the literature are also given.

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1. Introduction

A set of sensor nodes that form a network is a Wireless Sensor Network (WSN). It is intended for the sensing and provision of the data needed. In several real time systems, it is used. In fact it became ubiquitous. A sensor is basically a device which gathers data from environment or physical conditions like light, heat, pressure, temperature and so on. Its utility is purely based the purpose for which sensors are built. An electrical signal is typically an output of a sensor which is transmitted to controller where it is processed. Due to its popular usage in plethora of applications, it became of the important research areas. Multiple sensor nodes are involved in gathering data and forwarding it to base station. A typical WSN is shown in Fig. 1. Each node may act as transceiver. It can receive data and forward it to next node or base station. Sensor nodes do have limited resources while the base station is the node which is high in resources.

As the sensor nodes are devices that work with battery power and often deployed in even hostile environments, they have many limitations. They include very little storage and processing power such as few hundred KBs and 8 MHz respectively. The nodes do have short communication range and consume more power for communication. Energy is limited as nodes are battery powered. The life time is finite and the nodes may exhibit mobility as well. Nevertheless, WSN has many applications. The applications range from monitoring environment to performing sensing activities in Internet of Things (IoT) integrated smart applications.

As shown in Fig. 2, WSN has many real time applications. They are used in surveillance applications. With multimedia streaming capabilities, they are also used in entertainment. WSN is an essential part of IoT based smart applications like smart buildings, smart cities and so on. They are also used for security and surveillance purposes. WSN is useful in realizing precision agriculture and tracking of animals. It is very useful in healthcare applications as there are wearable sensor devices that are used to monitor health of patients.

There are different types of WSNs that can be deployed in different circumstances. Based on the deployment location, they are known as terrestrial WSN, underwater WSN, underground WSN, multimedia WSN and mobile WSN. Terrestrial WSN may have thousands of nodes effectively covering Goal field and data transfer to the base station. Underground WSN is costly and it is used to capture data from beneath the earth. Water sensors work from within water bodies while multimedia sensors can capture text, audio, video and images for tracking and monitoring. Mobile WSN on the other hand provided mobility. As follows, the article is organised. Section 2 offers the definition of the discovery of neighbours in WSN. Section 3 offers essential neighbourhood discovery protocols. Section 4 presents summary of neighbor discovery protocols. Section 5 covers performance comparison among

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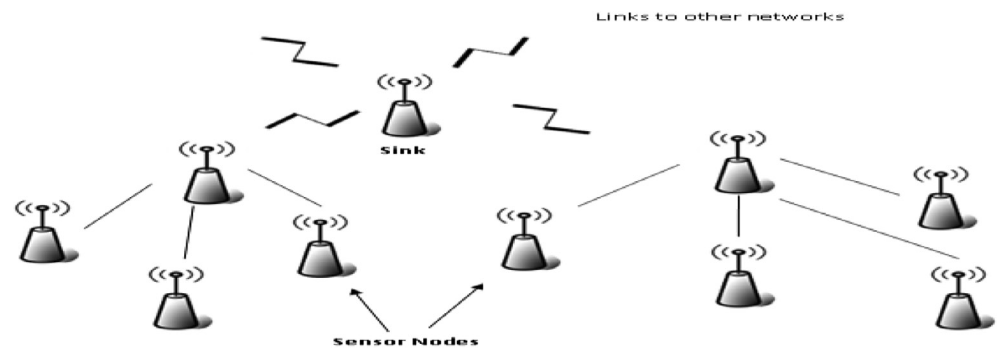

Fig. 1. A typical WSN with sensor nodes and base station or sink.

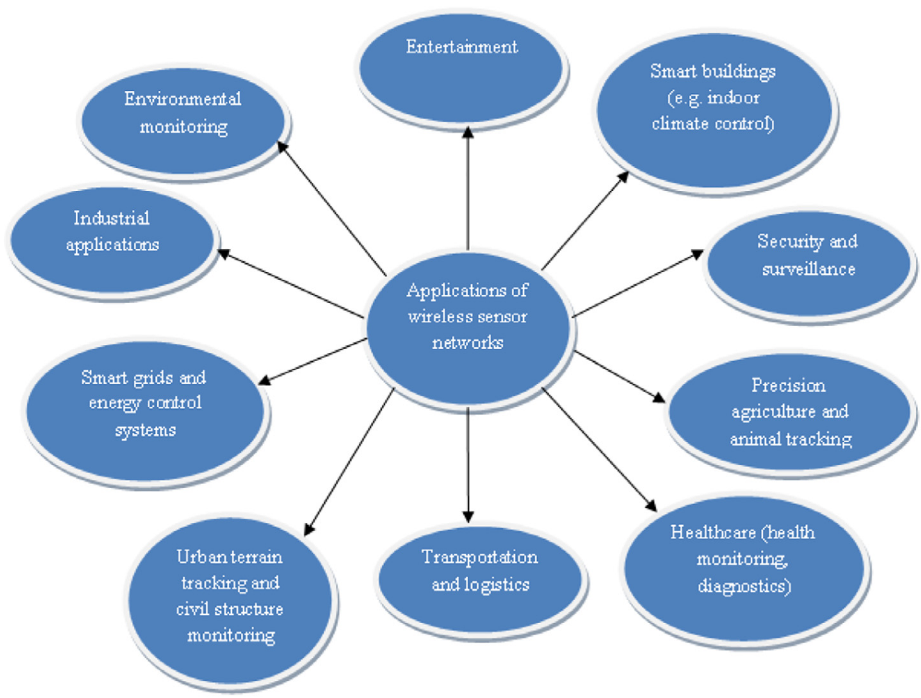

Fig. 2. Shows variety of real world applications of WSN.

different NDP. Section 6 covers the research gaps found in the literature. Conclusions and guidance for future work are given in Section 7.

2. Neighbor discovery in WSN

In WSN, neighbor discovery assumes importance for effective communications. Since WSN supports dynamic addition of new nodes and departure of existing nodes, the neighbors of a sensor node are not static. They may change dynamically and it is essential to discover neighbors. There are concepts of Original exploration of the neighbour and ongoing discovery of the neighbour. Fig. 3 presents neighbor discovery process and later on we discuss the difference from the original discovery of neighbours and the ongoing discovery of neighbours.

As shown in Fig. 3, it is evident that the node b sends HELLO which is not heard by other nodes. However, the nodes a and c discover each other. In order to discover nodes the following are essential operations. Whenever a node wakes up, it has to broadcast HELLO message. Any node that is already awake can hear that HELLO message to have connection established to the sender of the message. As shown in Fig. 4, node a is able to receive HELLO from the node c. That way they are able to discover each other. However, the nodes a and c are not aware of the presence of b and vice versa. This indicates the need for neighbour discovery.

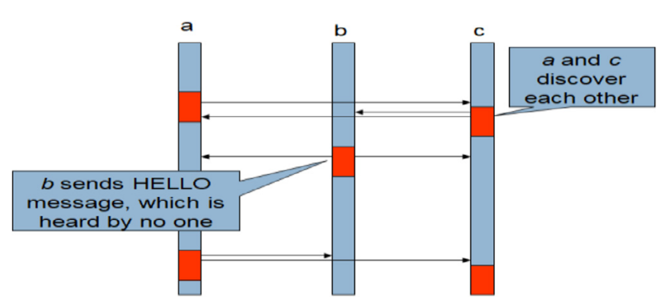

Fig. 3. Process of neighbour discovery.

2.1. Initial neighbor discovery

A sensor node performs initial discovery when it has no information about its neighbors. Before doing this, the sensor node also

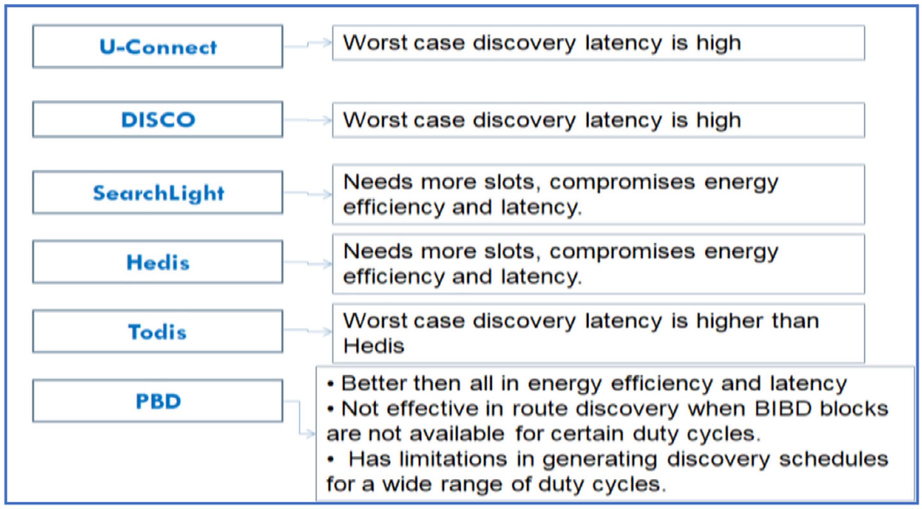

Fig. 4. Summary of findings.

cannot communicate with base station. Therefore it's functioning and usefulness is limited. Therefore, there is need for initial neighbor discovery and establish connectivity to base station. Since it is important, the energy usage for discovery is justified as it is only once. However, when the node is operational, it needs to perform continuous discovery from time to time as long as the node lives in the network. Therefore, optimization of continuous neighbor discovery is crucial for improving the lifetime of network.

2.2. Continuous neighbor discovery

Before performing continuous neighbor discovery, the node is well aware of its immediate neighbors. Therefore, this operation is made together with already known neighbors in order to reduce energy consumption. On the contrary, each node has to execute initial neighbor discovery separately. The purpose of continuous neighbor discovery is to detect all neighbor nodes and also find shortest path data transfer. As the sensor nodes are randomly deployed in some geographical area, initial neighbor discovery is done once when a sensor is deployed. However, continuous neighbor discovery is needed due to disruption of wireless connectivity and loss of local synchronization due to clock drifts.

3. Neighbor discovery schemes

There are many neighbor discovery approaches found in the literature. This section provides review of them.

3.1. U-Connect

Kandhalu et al. [9] proposed U-connect which are a low-latency asynchronous neighbor discovery protocol with energy efficiency. U-connect is designed and its latency is characterized and its power consumption is analyzed. Then it is evaluated with power-latency metric. U-connect is believed to be a unified protocol that is able to address neighbor discovery in two settings. They are called symmetric and asymmetric problems. In the process, two nodes can choose m different prime numbers for discovering neighbors. When same pair of prime numbers is used by nodes, a worst case latency performance is analyzed.

In order to have better performance U-connect characterizes network and neighbor discovery schedules. The latency discovery is associated with the following.

U- ψ u (m, t) = 1, if [t] p = 0 or $0 \leq$ [t] p 2 < 0, otherwise p + 1 2 (13)

Here the prime number is denoted as p. The case is considered where $p > 2$ for simplicity. The U-connect protocol is designed in such a way that it works well with worst case latency which is high in nature. The simulation study revealed that U-connect provides guarantee for a common active slot. Other advantages of U-connect include improved latency and energy efficiency.

3.2. Disco approach

This approach is explored by Dutta and Culler [8]. In WSNs, the low-power systems that are awake at different times need to discover neighbors. In such cases, the nodes need to use their radios at low duty cycles. This is the requirement in order to maximize lifetime of the WSN. It also needs to be vigilant about the emergence of new links and disappearance of old links. The two activities are not odds as vigilance and low-power operations are contradicting. In such networks Disco is the solution provided to have asynchronous neighbor discovery and solve the problem of rendezvous scheduling. The underlying method in Disco chooses two prime numbers in such a way that their reciprocal's sum is equal to the duty cycle of an application in question.

3.3. Hedis and Todis

These are the two neighbor discovery protocols proposed by Chen et al. [28]. Hedis stands for heterogeneous discovery as a quorum based protocol while Todis stands for Triple-Odd based discovery as a co-primality based protocol. These two protocols guarantee the process of asynchronous neighbor discovery. They operate in heterogeneous environments with different duty cycles used by each node. The granularity of duty cycles is optimized in order to have better performance. Actual duty cycles are matched by Hedis as it is an optimal quorum based approach. According to the design of Hedis schedule, node a with given duty cycle the schedule is considered as sa={sta}0 $\leq$ t < n(n − 1) which has n(n-1) time slots. Hedis and Todis are evaluated with different number of consecutive odd integers for building a wake-up schedule.

3.4. SearchLight

It is a matrix based neighbor discovery protocol. It is simple to be built. However, it compromises latency and energy efficiency. It

Table 1
Summary of neighbor discovery techniques.

REF	TECHNIQUES	ADVANTAGES	LIMITATIONS	SIMULATION TOOL
[7,33,35]	For asynchronous wake-up schedules, optimum block configuration	Scalability, energy efficiency and higher PDR	Further optimization is desired	NS2
[36]	Code based approach to ND	Different metrics and trade-offs between power and latency are known.	Further optimization is desired	TOSSIM
[37]	Code based approach to ND	Improved latency	Latency needs to be reduced further.	Simulation study
[3,7,31,32,33,38]	Block design based ND	Enhanced latency performance and energy efficiency.	Energy consumption needs to be reduced further	TOSSIM
[23,32,39]	Nested Block Design based ND for WSN	Low latency	Latency needs to be reduced further.	Statistical simulations with R tool
[5,40]	Integer and non-integer schedules for duty cycles	Energy efficiency and reduced latency	Needs to improve worst case latency	Simulation study
[7]	Cod based ND approach	Improved worst case latency	Worst case latency has to be reduced further.	Simulation study
[2,3,4,5,6,7,8,9,13,16]	DISCO protocol	Enhanced efficiency and latency of electricity	Latency for the worst case is also strong	Simulation study
[2,3,4,5], [7,9,10,12,13,19,26,32]	U-Connect protocol	Ensures a standard active slot, increased latency , energy consumption,	Latency for the worst case is also strong	Simulation study
[1,2,4,5,7,11,12,13,14,16, 19,20,26,29,31,32,33,41]	SearchLight	Matrix based solution, simple for implementation	Compromises energy efficiency and latency	Simulation study
[4,28]	Hedis and Todis protocols	Low error rate	It needs more slots and compromises energy efficiency and latency.	Simulation study
[32]	Prime Block Diagram	Improved energy efficiency and reduced the delay of the worst case.	When BIBD blocks are not eligible for those service cycles, they are not successful in route exploration.Has a constraint on a wide variety of service cycles in producing exploration schedules.	Simulation study with TOSSIM

uses matrix to have neighbor discovery schedules. SearchLight [16] is an asynchronous neighbor discovery protocol. It is built based on three ideas that are basis. It improves periodic awake slots and for probing. It facilitates awake slots to cover large time window. It has capabilities to use probabilistic techniques.

3.5. Prime Block design based neighbor discovery

Lee et al. [32] proposed a neighbor discovery protocol based on the concept of prime block design (PBD). It provides a near optimal solution for asynchronous wakeup cycles in WSN. It is an extension to its predecessor known as Balanced Incomplete Block Design (BIBD). The PBD works well with both symmetric and asymmetric duty cycles. It adds less number of duty cycles in excess to that of BIBD for performance improvement. Its advantage is that it is more efficient than other protocols. However, it has certain limitation. It is the lack of availability of BIBD blocks certain duty cycles.

3.6. Other neighbor discovery approaches

Code based approach [1], survey of neighbor discovery protocols [2,11,12,14,20,29,31], block design based protocols [3], energy efficient neighbor discovery [4], asynchronous neighbor discovery in duty cycled networks [5] and neighbor discovery in cognitive radio networks [6] are found in the literature. Other approaches found include a generic flexible protocol [10], smart phone neighbor discovery [13], secure neighbor discovery [15], adaptive neighbor discovery [16], quorum based approach [17], fast neighbor discovery [18], neighbor discovery and link quality estimation [19], low power neighbor discovery [21], broadcast foreigner discovery [12], x-raying neighbor discovery [22], neighbor discovery in 3D scenarios [23], neighbor discovery for security [24], multi-packet reception based neighbor discovery [25], multi-channel neighbor discovery [26] and heterogeneous neighbor discovery [27]. Neighbor discovery for opportunistic networking [30], group-based neighbor discovery [33] and continuous neighbor discovery in asynchronous sensor networks [34] are other approaches found in the literature.

4. Summary of important techniques found in literature

This section provides some of the important approaches found in the literature. It provides the techniques used by researchers, their advantages, limitations and the simulation environment used by them.

As presented in Table 1, many neighbor discovery protocols are summarized. From the review of these techniques, the following are the research gaps identified.

5. Discussion and research gap

As presented in Table 1, many neighbor discovery protocols are summarized. From the review of these techniques, the following are the research gaps identified.

This section provides the summary of findings with respect to recent State of the art on the continuous exploration of neighbours in WSN. The schemes or protocols summarised here include U-Connect, DISCO, SearchLight, Hedis, Todis, and PBD. Each protocol has its advantages and limitations as provided in Table 1. Fig. 4 presented in this section throw light into important drawbacks of each neighbour discovery scheme. In other words, the research gap associated with each scheme is provided.

As presented in Fig. 4, it is evident that the existing neighbour discovery method known as Prime Block Design (PBD) [12] extends Protocol focused on Balanced Incomplete Block Architecture (BIBD) [1]. The primary concern with PBD is that when BIBD blocks are not eligible for such service cycles, it is not successful in route exploration. In addition, the generation of exploration schedules for a wide variety of service cycles has limitations. This is the challenging problem to be addressed. Our future work focuses on overcoming the drawbacks of PBD method used for neighbour discovery.

6. Conclusion and future work

Wireless Sensor Network intended to have long term monitoring applications should have an efficient neighbor discovery protocol. During deployment of sensor networks it is very important and challenging task to discover neighbors. Neighbor discovery is a continuous process in WSN. After initial setup of a network, at any point of time, a set of new sensor nodes may be deployed. With continuous neighbor discovery, energy and latency are affected unless the discovery process is optimized. This paper has made review of different ND techniques. The existing neighbor discovery method known as Prime Block Design (PBD) extends protocol focused on Balanced Incomplete Block Architecture (BIBD). The key concern with PBD is that when BIBD blocks are not usable for several service cycles, it is not successful in neighbour exploration. In addition, the generation of exploration schedules for a wide variety of service cycles has limitations. This is the challenging problem to be addressed by considering it for our future work.

CRediT authorship contribution statement

B. Sravankumar: Conceptualization, Methodology, Software, Visualization, Writing - original draft. **Nageswara Rao Moparthy:** Data curation, Supervision, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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