Alano: May You Discover Your Neighbors

***Abstract*—The abstract goes here.**

..

..

..

..

..

..

..

..

..

..

..

..

..

..

..

..

..

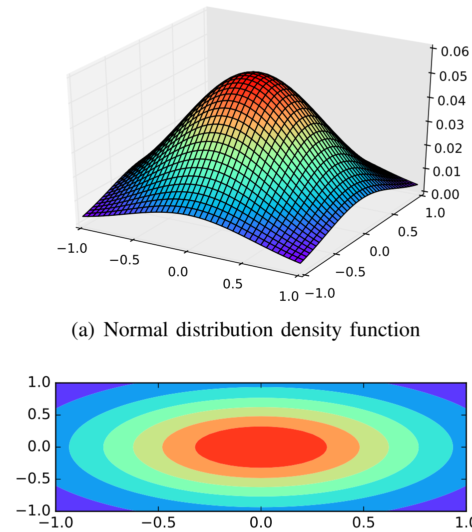
..

..

..

..

..



(a) Normal distribution density function

(b) Network obeys normal distribution

Fig. 1. An example of a network obeying normal distribution.

I. Introduction

Information and Communication Technology (ICT) equipment has exploded on the scene in the last twenty years [1]. Varying from their specific applications, these devices consists of a wide variety of networks.

Neighbor discovery is a fundamental means for the devices to participate in network communication. A popular way to deal with this issue is to construct a deterministic sequence of transmission state in each time slot [2]–[8]. It holds an obvious advantage that the time to discovery a neighbor node can be bounded within a limited time. Nevertheless, most deterministic approaches only consider two nodes to discover each other, without further deliberating on the details (e.g. collisions from neighbors) when applying for multi-nodes. Instead, there are some probability based algorithms showing an ideal expected time bound for multi-nodes to find their neighbors. However, the weakness part of this kind of methods lies in the poor performance of discovery latency in the worst case.

A more crucial issue is that neither deterministic or probabilistic approaches consider a partially-connected networks in reality, the devices of which can only possess a fraction neighbors among all the nodes. Deploying a fully-connected network in a large-scale area, such as campus networks, wireless sensor networks, mobile gaming community, etc., is technically impractical due to the limited sensing range of devices communication. How far the other nodes can be detected as a neighbor for a mobile equipment depends on criterion such as the received signal strength. Thus a practical situation is that in a network , the nodes are partially connected with its detectable neighbors.

*********To be dealt with details later********

How we deal with partially-connected networks:

1. Consider distribution of network devices: uniform distribution normal distribution

2. propose a distribution based Alano alogrithm

*

*

*

*

***Motivation of energy-efficient networks:**

Among the partially-connected networks, there is a special one named energy-efficent network. Nodes in this type of networks have to maintain strict power budgets to attain years of lifetime [9]. Duty circle mechanism, the , is utilized to power-awareness ought to be fully taken into consideration. Correspondingly, the neighbor discovery process needs adjustment to deal with the dilemma between a balance of energy-efficiency and low- latency.

Contribution conclusion

In this paper, we first focus on the mathematical analysis of the distribution of the nodes in the networks. We give a expectation of neighbor number for each node in a network which obey**** propose Alano[1], a RDS-Alano algorithm for partially-connected networks as well as a TP-Alano algorithm for the energy-effienct networks.

The contributions of this paper are as follows:

1) We model the distribution of nodes in their networks and analyse the expectation number of neighbors of a node in uniform distribution and normal distribution and then propose Alano, a strategy
2) We propose a Relaxed DifferenceSet based Alano algorithm (RDS-Alano) for the global duty circle scenario.
3) We propose a Traversing Pointer based Alano algorithm (TP-Alano) for the local duty circle scenario.

***Rest part structure**

The remainder of the paper is organized as follows. The next section highlights some related work and puts forward some serious problems. Some notion definitions and the system model are given in Section III. We analyse the node's expectation number of neighbors and propose Alano algorithm in IV as a foundation. Section V describes the RDS-Alano algorithm for global duty circle scenario and TP-Alano algorithm for local duty circle scenario respectively in energy-efficient networks. We have conducted extensive simulations, and the results are shown in Section VI. Finally, we conclude the paper in Section VII.

II. Related Work

Introduce the representative existing algorithms.

1. Birthday Alg.
2. BlindDate Alg.
3. Disco Alg.
4. Hello Alg.
5. Searchlight Alg.
6. Talk More Listen Less Alg.
7. Todis&Hedis Alg.
8. U-Connect Alg.
9. ALOHA-like Alg.

(Note : Introduction and Related Work are expected to be 2 pages)

III. Preliminaries

In this section, we first describe the network and node model. Then we formulate the Neighbor Discovery problem formally.

A. Network and Node Model

In a network, the location of the nodes are likely to obey uniform distribution[][], Gaussian distribution[][] or other combinatorial distributions.

In reality, since the network is deployed in a vast area, each node has a capacity to sense a fraction of nodes within its sensing range. These networks are defined as *Partially-Connected Networks*.

Among the partially-connected networks, there is a particular type called *Energy-Efficient Networks*. A typical one of energy-efficient networks is the wireless sensor network. The wireless sensor network consists of a number of sensors distributed separately in a target area. The deployed sensor nodes keep their most time in sleep pattern to avoid quick energy consumption and wake up timely to work on duty.

When a node wake up on a time slot, it can turn to either the transmitting state or listening state.

- **Transmitting state**. A node turn to transmitting state will broadcast a package containing its own identify information to all neighbors.
- **Listening state**. A node turn to listening state will monitor the frequency channel to collect its neighbors' packages. However collision will occur when two or more neighbor nodes transmit concurrently and thus no valid information will be gathered

Transiting between the states only costs little time, compared to one complete time slot.

In our model, we denote the node set in the network as $U = \{u_1, u_2, ..., u_N\}$. Time is divided into slots of equal length t_0, which is sufficient to finish one communication process (transmit or receive a piece of package). In each time slot, a node transform its pattern according to a pre-defined duty schedule.

Definition 1: **Duty Schedule** is a pre-defined sequence $S = \{s^t\}_{0 \le t < T}$ of period T and

$$s^t = \begin{cases} S & Sleep \\ T & Transmit \\ L & Listen \end{cases}$$

Each node construct its own duty schedule according to a specific strategy and repeats it until finding all the neighbors. Since the waking-up duration has a significant affect on the battery's lifetime, duty circle is utilized to restrict the energy consumption.

Definition 2: **Duty Circle** represents the fraction of one period T where a node turns its radio on. It can be formulated as:

$$\theta = \frac{|\{t : 0 \le t < T, s^t \in \{T, L\}\}|}{T}.$$

A homogeneous energy-arrangement case is that all the nodes in the network share a common global duty circle θ, while each nodes holding a local duty circle θ_i is a heterogeneous

B. Problem Definition

We consider a partially-connected network, where two nodes are neighbors if they locate within the radio range of each other. A symmetric matrix $M_{N\times N}$ is used to record the neighboring relations as:

$$M_{i,j} = \begin{cases} 1 & connected \\ 0 & disconnected \end{cases}$$

Each node follows its duty schedule to achieve neighbor discovery. In a synchronous scenario, nodes start their neighbor

[1]Alano is the god of luck in Greek mythology

discovery process at the same time, while in a asynchronous scenario all nodes start at different time slots. We focus on the asynchronous case while still applicable for the synchronous situation.

Notice that the neighbor discovery process is not bidirectional, which means any pair of neighbors need to find each other separately. The time slots within which a node u_i find one of its neighbors u_j can be formulated as $L(i,j)$. Then we define the discovery latency that node u_i discovers all neighbors as:

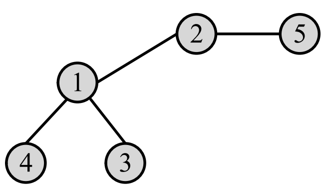
Definition 3: **Discovery Latency** of node u_i is the time to discover all neighbors:

$$L(i) = \max_{j:M_{i,j}=1} L(i,j).$$

Thus the neighbor discovery problem can be formulated as:

Problem 1: For a node u_i with its neighbor set $S = \{u_{i1}, u_{i2}, ...u_{ij}, ...\}$, design a strategy to construct a duty schedule, which satisfies $\forall$ neighbor nodes u_{ij} :

$$\exists t \ s.t.: \quad S_i(t) = L, S_{ij}(t) = T, \forall k \neq j : S_{ik}(t) \in \{L, S\}.$$



(a) The topology of a wireless sensor networks

Time	...	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	...
Node 1			T	S	S	S	S	S	L	S	S	L	S	S	S	T	...
Node 2			S	S	L	S	S	S	T	S	L	S	S	S	S	L	...
Node 3	...	S	S	S	T	S	S	S	T	S	L	S	S	S	L	S	...
Node 4				S	S	S	S	S	S	S	S	S	T	T	T	T	...
Node 5							S	S	L	S	S	S	T	S	S	S	...

(b) Neighbor discovery process

Fig. 2. An example of neighbor discovering process. S, T and L represents Sleep pattern, Transmitting state and Listening state in wake-up pattern respectively.

An example of neighbor discovery process is given in Fig.2. Fig.2(a) shows the topology of a partially-connected wireless sensor network, which consists of 5 sensor nodes. Fig.2(b) describes the neighbor discovery process in the asynchronous scenario, as we can see the nodes start their process at different time slot. The duty schedule of node 1, for example, is $S_1 = \{1, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 1, ...\}$. At time slot 12, node 5 find its neighbor node 2 while node 1 could not find node 2 due to a collision from its another neighbor node 3.

IV. Partially-Connected Networks

A practical scenario is that in a network, all the nodes are partially connected with each other. A node can discover a fraction of nodes within its sensing range.

In a partially-connected network for $\forall$ node u_i, its position coordinate (x_i, y_i) obeys a certain probability distribution depending on the characteristic of the network, with the density function as :

$$f(x,y) = \begin{cases} \varphi(x,y) & (x,y) \in D \\ 0 & (x,y) \notin D \end{cases}$$

where D is the network covering area.

$\forall$ node $u_i(x_i, y_i)$, its sensing range area R_i can be formulated as:

$$(x - x_i)^2 + (y - y_i)^2 \leq r^2$$

where r is the detection radius.

Thus, we can obtain the expected number of neighbors of node u_i as :

$$NB(u_i) = N \iint_{R_i} f(x,y)\, dx\, dy - 1.$$

We ignore the boundary area of the network and assume the nodes in the network is of an enormous quantity, so the expectation neighbors can be formulated as:

$$NB(u_i) = N \iint_{R_i} \varphi(x,y)\, dx\, dy.$$

Note that, when the network area is far more larger than the sensing area of the nodes, we can approximately get:

$$NB(u_i) = N\pi r^2 \varphi(x,y).$$

Then we propose **Alano**, a randomized neighbor discovery algorithm. We describe the algorithm for $\forall$ node u_i in Alg. 1. Alano algorithm indicates that what probability for a node choose to turn to tramisitting state or listening state is determined by the expectation neighbor number varying from node to node.

Algorithm 1 Alano Algorithm

```
1:  n̂_i = N ∬_{R_i} φ(x,y) dx dy;
2:  p_t^i = 1/n̂_i;
3:  while True do
4:      A random float ε ∈ (0,1);
5:      if ε < p_t then
6:          Transmit a message containing node information of u_i;
7:      else
8:          Listen on the channel and decode the node information if receive a message successfully;
9:      end if
10: end while
```

In the following section IV-A, we first consider a general situation that the nodes in the network are uniform distributed. We derive a proof that the probability chosen in Alano is the optimal one and show the bounded latency will not be much larger than its expectation. Then in the section IV-B we describe a more common situation that the nodes in the network obey Gaussian Distribution, we present a approximation analysis that the discovery latency will not be much larger than uniform distribution.

A. Uniform Distribution

There are a part of partially-connected networks obeying uniform distribution. For instance, consider there is a wireless sensor network carrying out a task of measuring temperature and humidity in a target area, thus the sensors are supposed to be evenly deployed and the density function can be formulated as:

$$f(x) = \begin{cases} \frac{1}{A} & (x,y) \in D \\ 0 & (x,y) \notin D \end{cases}$$

where A is the area of D.

Every node in the network has the same expectation of neighbor number and transmit with the same probability as:

$$\hat{n} = \frac{N\pi r^2}{A}, \quad p_t = \frac{1}{\hat{n}} = \frac{A}{N\pi r^2}.$$

According to Alano, the probability that node u_i discover a specific neighbor successfully in a time slot can be formulated as:

$$p_s = p_t(1-p_t)^{\hat{n}-1}.$$

Let:

$$p_s' = (1-p_t)^{\hat{n}-1} - (\hat{n}-1)p_t(1-p_t)^{\hat{n}-2} = 0.$$

It is easy to confirm that when

$$p_t = \frac{1}{\hat{n}}.$$

p_s gets the maximum value:

$$p_s = \frac{1}{\hat{n}}(1-\frac{1}{\hat{n}})^{\hat{n}-1} \approx \frac{1}{\hat{n}e}.$$

Thus we can conclude that the probability chosen in Alano to transmit is the optimal one.

Next we analyse the expectation latency for a node to discover all its neighbors. We denote W_j to be a random variable representing the number of the time slots needed to discover a new neighbor after $(j-1)$ neighbors have been discovered, which follows Geometric distribution with parameter $p(j) : p(j) = (\hat{n}-j+1)p_s$. Then the expectation of W_j is computed as:

$$E[W_j] = \frac{1}{p(j)} = \frac{1}{(\hat{n}-j+1)p_s}$$

The expectation time latency of discovering all the neighbors can be formulated as:

$$E[W_j] = \sum_{j=1}^{\hat{n}} \frac{1}{p_s} H_n \approx ne(lnn + \Theta(1)) = \Theta(nlnn).$$

where H_n is the n-th Harmonic number, i.e., $H_n = lnn + \Theta(1)$.

We get the expectation discovery latency is within O(nlogn) and then we show the bounded latency will not be much larger than its expectation.

If W_i is given, the value of W_j will not be affected for $i < j$. That is, for $i \neq j$, W_i and W_j are independent and they satisfy $P(W_j = w_j | W_i = w_i) = P(W_j = w_j)$. Since W_j follows Geometric distribution, and $Var[W_j] = \frac{1-p_j}{p_j^2}$, the variance of W is

$$Var[W] = \sum_{j=1}^{n} Var[W_j] \leq \frac{\pi^2}{6p_{suc}^2} - \frac{H_n}{p_{suc}}.$$

With *Chebyshev's inequality*, the probability that the discovery time is 2 times larger than the expectation is

$$P[W \geq 2E[W]] \leq \frac{Var[W]}{E[W]^2} \leq \frac{\pi^2}{6H_n^2} - \frac{p_{suc}}{H_n}.$$

For large n, $P[W \geq 2E[W]]$ is close to 0. That is, the time for a node to find all neighbors is very likely to be smaller than 2 times of expected latency. Therefore,

$$W = O(nlnn).$$

B. Gaussian Distribution

A common scenario is that the nodes in a network obey 2D Gaussian distribution. For example, an intrusion detection application may need improved detection probability around important entities [10].

In this section, we present a theoretical proof that the latency performance will not be much larger than uniform distribution. The analysis is not only applicable for Gaussian distribution but also flexible for all the other distributions.

We first denote the approximate neighbors of node u_i as set $S(u_i) = \{u_{i1}, u_{i2}, ..., u_{i\hat{n_i}}\}$. When the nodes obey Gaussian distribution, according to Alano, the probability that node u_i discovers a certain neighbor node u_{ij} successfully in a time slot can be formulated as:

$$p_{suc} = (1-p_t^i)p_t^{ij} \prod_{k=1}^{\hat{n_i}, k\neq j} (1-p_t^{ik})$$

Denote:

$$p_t^{imax} = \max_{1\leq j\leq \hat{n_i}} \{p_t^{ij}\}, \quad p_t^{imin} = \min_{1\leq j\leq \hat{n_i}} \{p_t^{ij}\}.$$

Thus for $\forall j$, $1 \leq j \leq n_i$:

$$\begin{aligned} &(1-p_t^i)p_t^{imin}(1-p_t^{imax})^{\hat{n_i}-1} \\ \leq &(1-p_t^i)p_t^{ij} \prod_{k=1}^{\hat{n_i}, k\neq j} (1-p_t^{ik}) \\ \leq &(1-p_t^i)p_t^{imax}(1-p_t^{imin})^{\hat{n_i}-1} \end{aligned}$$

Denote:

$$\begin{aligned} P &= (1-p_t^i)p_t^{imin}(1-p_t^{imax})^{\hat{n_i}-1} \\ Q &= (1-p_t^i)p_t^{imax}(1-p_t^{imin})^{\hat{n_i}-1} \end{aligned}$$

Thus we get:

$$\begin{array}{ccccc} \frac{1}{\hat{n_i}Q} & \leq & E[W_1] & \leq & \frac{1}{\hat{n_i}P} \\ \frac{1}{(\hat{n_i}-1)Q} & \leq & E[W_2] & \leq & \frac{1}{(\hat{n_i}-1)P} \\ & & .... & & \\ \frac{1}{Q} & \leq & E[W_{\hat{n_i}}] & \leq & \frac{1}{P} \end{array}$$

Sum all the equations above, and we will get:

$$\frac{1}{Q}H_n \quad \leq \quad E[\sum_{j=1}^{\hat{n_i}} W_j] \quad \leq \quad \frac{1}{P}H_n$$

Since the sensible neighbors are within a close distance of the node compared to the total network area, which implies the density function values are within the same order of magnitude. Thus we can conclude that the expectation of the time latency in the normal distributed networks are still $E[W] = O(nlnn)$. Similarly the bounded latency can be proved to be $W = O(nlnn)$ in the same way as uniform distribution.

V. Energy-Efficient Networks

In an energy-efficient network (i.e., wireless sensor networks), the battery-consumption is a crucial factor to be taken into account. Duty circle is a key technique to deal with the dilemma between a balance of energy-efficiency and low-latency.

We first consider the homogeneous energy-arrangement situation that all the nodes share a global duty circle θ, and propose a RDS based Alano algorithm. Then we propose a traversing pointer based Alano algorithm for a more general scenario, where nodes have heterogeneous battery-scheduling capability with local duty circle θ_i.

Our initiative idea is to align the wake-up slots of the neighbor nodes within a bounded time, and then invoke the Alano algorithm to achieve neighbor discovery process w.h.p. More specifically, we utilize the property of RDS and traversing pointer to guarantee a wake-up slot rendezvous in each period T.

A. Global θ: A RDS Based Alano Algorithm

When a global duty circle θ is shared by all the nodes in the network, we utilize relaxed difference set (RDS) to align the wake-up time slots.

Relaxed difference set (RDS) is an efficient tool to construct cyclic quorum systems [11], [12]. The definition can be described as:

Definition 4: A set $R = \{a_1, a_2, ..., a_k\} \subseteq Z_n$ (the set of all nonnegative integers less than n) is called a Relaxed Difference Set (RDS) if for every $d \neq 0$ (mod n), there exists at least one ordered pair (a_i, a_j) such that $a_i - a_j \equiv d$ (mod n), where $a_i, a_j \in D$.

It has been proved that any RDS must have cardinality $|R| \geq \sqrt{N}$ [12]. We present a simple linear algorithm for RDS construction under Z_N with $\lceil \frac{3\sqrt{N}}{2} \rceil$ cardinality in Alg. 2.

The initiative idea of Alg. 2 can be described as Fig. 3. The framed elements are selected as in Alg. 2 Line. 4 and Line. 7.

We give a formal correctness proof of the construction as following:

Theorem 1: The set $R = \{r_0, r_1, ..., r_{\lambda+\mu-1}\}$ constructed in Alg. 2 is a RDS, where $|R| = \lambda + \mu = \lceil \sqrt{N} \rceil + \lceil \frac{\lceil \sqrt{N} \rceil}{2} \rceil \approx \lceil \frac{3\sqrt{N}}{2} \rceil$.

Algorithm 2 RDS construction under Z_N

1: $R := \emptyset$;
2: $\lambda := \lceil \sqrt{N} \rceil$,$\mu := \lceil \frac{\lceil \sqrt{N} \rceil}{2} \rceil$;
3: **for** $i = 1 : \lambda$ **do**
4: $\quad R := R \cup i$;
5: **end for**
6: **for** $j = 1 : \mu$ **do**
7: $\quad R := R \cup (1 + j * \lambda)$;
8: **end for**

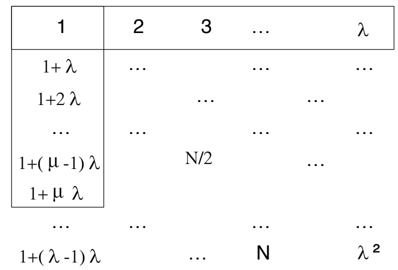


Fig. 3. An Sketch of RDS construction in Alg. 2

Proof: We first reach a consensus that if there exists one ordered pair (a_i, a_j) satisfying $a_i - a_j \equiv d$ (mod N), then we can get an opposite pair (a_j, a_i) such that $a_j - a_i \equiv (N - d)$ (mod n). Thus we only need to find at least one ordered pair (a_i, a_j) for each d from 1 to $\lfloor N/2 \rfloor$.

The λ in Line 2 is the smallest integer satisfying $\lambda^2 \geq N$. Then every d from 1 to $\lfloor N/2 \rfloor$ can be represented as: $d = 1 + j \times \lambda - i$, where $1 \leq j \leq \mu, 1 \leq i \leq \lambda$. Thus there exists $a_j = 1 + j \times \lambda$ added in Line. 4 and $a_i = i$ added in Line. 7 satisfying $a_j - a_i \equiv d$. ■

Next, we present a RDS based Alano algorithm (RDS-Alano) in Alg. 3, to achieve neighbor discovery process in a partially-connected and energy-efficient network with global duty circle θ.

In Alg. 3, RDS is used to construct a deterministic schedule for the node to wake up in every period T, and Alano is utilized as a probabilistic strategy to determine the transmission state (transmit or listen) in each wake-up slot.

Algorithm 3 RDS Based Alano Algorithm

$T := \lceil \frac{9}{4\theta^2} \rceil$;
Invoke Alg. 2 to construct the RDS $R = r_0, r_1, ..., r_{\lceil \frac{3\sqrt{T}}{2} \rceil}$ under Z_T;
$t := 0$;
while $True$ **do**
$\quad$ **if** $(t + 1) \in R$ **then**
$\quad\quad$ Invoke Alg. 1 to determine transmission state;
$\quad$ **else**
$\quad\quad$ Sleep;
$\quad$ **end if**
$\quad$ t := (t + 1) % T;
end while

We show a proof of time latency bound for Alg. 3 as following:

Theorem 2: Alg. 3 guarantees the discovery latency to be bounded within $O(\frac{nlog}{\theta^2})$ w.h.p.

Proof: It is easy to confirm that the duty circle $\widetilde{\theta}$ in Alg. 3 corresponds to θ as:

$$\widetilde{\theta} = \frac{|RDS|}{|T|} = \frac{\lceil \frac{3\sqrt{T}}{2} \rceil}{T} = \theta.$$

For any pair of neighbors (node i, node j), we can find an ordered pair (r_i, r_j) from their respective RDS such that $r_i - r_j \equiv \delta_t$ (mode T), which indicates any neighbor pair can wake up in the same time slot at least once in every period T. Regarding the whole period T as a time slot in Alg. 1, we obtain the latency bound as $O(\frac{nlogn}{\theta^2})$. ∎

B. Local θ: A Traversing Pointer Based Alano Algorithm

For a more practical scenario, the nodes in a wireless sensor networks for instance, are assigned to diverse tasks such as temperature measurement, sunshine collection, etc., and thus ought to have heterogenous capability of battery-management with local duty circle θ_i.

We propose a traversing pointer based Alano algorithm(TP-Alano) in Alg. 4. In each period T, every node wakes up in two different time slots, one of which is the first slot of each period and another is a traversing slot different from period to period, as Alg. 4 Line . 5 indicates.

Algorithm 4 Traversing Pointer Based Alano Algorithm

1: T :=Find the smallest prime $\geq \frac{2}{\theta_i}$;
2: $t := 0$;
3: **while** $True$ **do**
4: $\quad t_1 := t\%T$;
5: $\quad t_2 := \lfloor t/T \rfloor \%(T-1) + 1$;
6: $\quad$ **if** $t_1 = 0 || t = t_2$ **then**
7: $\qquad$ Invoke Alg. 1 to determine transmission state;
8: $\quad$ **else**
9: $\qquad$ Sleep;
10: $\quad$ **end if**
11: $\quad t := t + 1$;
12: **end while**

We call the first time slot in each period T as a *fixed pointer* and the traversing slots as a *traversing point*. These pointers are used to guarantee a wake-up time rendezvous in every period T_iT_j. A sketch of the pointers is described in Fig. 4.

Note that, since the period of T is selected as: *find the smallest prime* $\geq \frac{2}{\theta_i}$, which is likely to result in the consequence that the duty circle $\widetilde{\theta_i}$ in Alg. 4 is smaller than the expected θ. This can be easily solved by selecting some random wake-up time slots in each period T to conform to duty circle θ.

We give a correctness proof of the time bound to achieve neighbor discovery process as following:

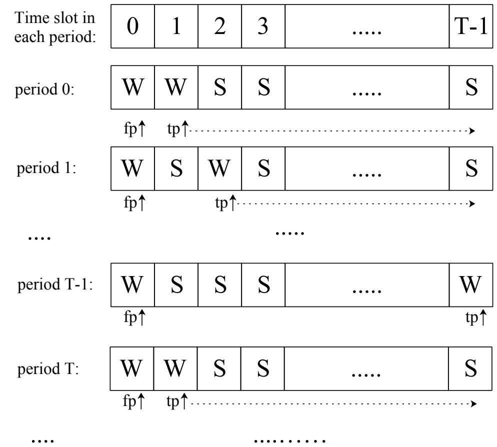


Fig. 4. An Sketch of TP construction in Alg. 4

Theorem 3: Alg. 4 guarantees the discovery latency to be bounded within $O(\frac{nlogn}{\theta_i\theta_j})$ w.h.p., where θ_i and θ_j are the duty circles of a pair of neighbors (node i,node$j$) respectively.

Proof: We first prove that any pair of nodes (node i,node$j$) will wake up at the same time slot every period T_iT_j.

Case 1: $T_i \neq T_j$. Since T_i and T_j are different primes, according to Chinese remainder theorem, there exists a time slot $t_\tau \in [0, T_iT_j)$ satisfying:

$$0 = t_\tau \quad mod \quad T_i. \tag{1}$$

$$\delta = t_\tau \quad mod \quad T_j. \tag{2}$$

where δ is the asynchronous drift between node i and node j.

Equation1 and 2 implies there exists a fixed pointer of node i and a fixed pointer of node j rendezvous in every T_iT_j .

Case 2: $T_i = T_j$. Since $T_i = T_j = T$, if the asynchronous drift between node i and node j $\delta = 0$, the fixed pointers of node i and node j will rendezvous with each other in every period T. Otherwise since the traversing point will traverse all the time slots once during period $(T-1)T$, there exists a traversing point of node i rendezvous with a fixed pointer of node j every period $(T-1)T$, and a traversing point of node j will consequentially rendezvous with a fixed pointer of node i once every period $(T-1)T$ as well.

Thus for any pair of neighbor (node i, node j), they can wake up at the same time slot at least once in every period T_iT_j. Regarding the whole period T_iT_j as a time slot in Alg. 1, we obtain the latency bound as $O(\frac{nlogn}{\theta_i\theta_j})$. ∎

VI. Evaluation

(Note : Evaluation is expected to be around 1 page)

VII. Conclusion

The conclusion goes here.

REFERENCES

[1] S. Zeadally, S. U. Khan, and N. Chilamkurti, "Energy-efficient networking: past, present, and future," *The Journal of Supercomputing*, pp. 1–26, 2012.

[2] K. Wang, X. Mao, and Y. Liu, "Blinddate: A neighbor discovery protocol," *IEEE Transactions on Parallel and Distributed Systems*, vol. 26, no. 4, pp. 949–959, 2015.

[3] Y. Qiu, S. Li, X. Xu, and Z. Li, "Talk more listen less: Energy-efficient neighbor discovery in wireless sensor networks," in *Computer Communications, IEEE INFOCOM 2016-The 35th Annual IEEE International Conference on*. IEEE, 2016, pp. 1–9.

[4] P. Dutta and D. Culler, "Practical asynchronous neighbor discovery and rendezvous for mobile sensing applications," in *Proceedings of the 6th ACM conference on Embedded network sensor systems*. ACM, 2008, pp. 71–84.

[5] W. Sun, Z. Yang, K. Wang, and Y. Liu, "Hello: A generic flexible protocol for neighbor discovery," in *INFOCOM, 2014 Proceedings IEEE*. IEEE, 2014, pp. 540–548.

[6] M. Bakht, M. Trower, and R. H. Kravets, "Searchlight: Won't you be my neighbor?" in *Proceedings of the 18th annual international conference on Mobile computing and networking*. ACM, 2012, pp. 185–196.

[7] L. Chen, R. Fan, K. Bian, M. Gerla, T. Wang, and X. Li, "On heterogeneous neighbor discovery in wireless sensor networks," in *Computer Communications (INFOCOM), 2015 IEEE Conference on*. IEEE, 2015, pp. 693–701.

[8] A. Kandhalu, K. Lakshmanan, and R. R. Rajkumar, "U-connect: a low-latency energy-efficient asynchronous neighbor discovery protocol," in *Proceedings of the 9th ACM/IEEE international conference on information processing in sensor networks*. ACM, 2010, pp. 350–361.

[9] A. Dunkels, "The contikimac radio duty cycling protocol," 2011.

[10] Y. Wang, W. Fu, and D. P. Agrawal, "Gaussian versus uniform distribution for intrusion detection in wireless sensor networks," *IEEE Transactions on Parallel and Distributed systems*, vol. 24, no. 2, pp. 342–355, 2013.

[11] J.-R. Jiang, Y.-C. Tseng, C.-S. Hsu, and T.-H. Lai, "Quorum-based asynchronous power-saving protocols for ieee 802.11 ad hoc networks," *Mobile Networks and Applications*, vol. 10, no. 1-2, pp. 169–181, 2005.

[12] W.-S. Luk and T.-T. Wong, "Two new quorum based algorithms for distributed mutual exclusion," in *Distributed Computing Systems, 1997., Proceedings of the 17th International Conference on*. IEEE, 1997, pp. 100–106.

(Note : Conclusion and Reference are expected to be less than 1 page)