A Circle-Based Data Dissemination Algorithm for Wireless Sensor Networks with Mobile Sink

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Abstract

The topic of reducing energy dissipation and prolonging network lifetime in Wireless Sensor Networks (WSNs) has attracted much attention of researchers. A primary obstacle is the hot spot issue which means data forwarding load for nodes near sink is too much and they usually die early. In this paper, we propose circle-based data dissemination (CBDD) algorithm which utilizes mobile sink to relieve hot spot phenomenon. We assume sensor nodes are symmetrically deployed in a circle sensor field and sink moves around the circle. The sink sends a query message to a specific node for sensed data, which begins a data gathering process. All the nodes belong to different layers according to the distance to sink and the queried nodes communicate with sink layer by layer. Simulation results prove that our algorithm achieves better balance between energy dissipation and network lifetime compared with conventional approaches with static sink.

Keywords: *mobile sink, circle sensor field, hotspot phenomenon*

1. Introduction

Nowadays both industry and academia pay much attention to Wireless Sensor Networks (WSNs) which consist of large numbers of sensor nodes. These densely deployed sensors are equipped with energy-limited batteries and usually fixed in unattended environment. They form a multi-hop self-organized network system via wireless communication. WSN is an intelligent information system which is widely applied in different fields thanks to its comprehensive nature. Some common occasions are environment monitor, transport system, smart home systems and so on.

Sensors in WSNs are limited in available energy, computing power and memory capacity and usually deployed randomly. Both ordinary sensor nodes and the sink are fixed in a certain location in conventional WSNs which use communication protocols based on single static sink like LEACH [1], GAF [2], HEED [3], ICRP [4]. The choice of route is one of the key points in WSNs as hot spot phenomenon always breaks balance between reducing energy dissipation and prolonging network lifetime. Hot spot issue is brought in two cases. One is that in order to minimize the total energy cost, we always choose a route which consumes relatively lower energy, consequently nodes along this route are accessed continually and their power are depleted earlier than other nodes in the network. The other case is that as sensor nodes are deployed randomly, the number of nodes near sink is much smaller than that of nodes far from sink such that when large amounts of data packets are sent towards sink, nodes near sink will become quite busy. Hot nodes have high communication load and they

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will use up their energy than other nodes. The nonuniform distribution of energy consumption leads to short network lifetime.

To solve hotspot issue of wireless sensor networks with fixed sink, many novel algorithms or mechanisms based on the model of wireless sensor networks with single or multiple mobile sinks emerges. Hot nodes mostly are those nodes near the sink and they suffer more energy consumption because of more communication traffic, namely high-load phenomenon. In WSNs with static sink, the high-load phenomenon is always happened on several nodes near the sink and these nodes die more quickly. Mobile sink can effectively move the high communication traffic from hot nodes to other less used nodes in order to make an even transmission load distribution.

As mentioned before, sensor nodes are deployed randomly in many cases. However, we need to deploy sensor nodes at specified position [5, 6]. For example, in farms, people deploy sensor nodes on the pasture field to gather data we are interested in or in areas that often suffer weather disasters, we can deploy sensor nodes when the area is in safe. We monitor events in area of interest with a mobile sink which is attached to mobile vehicle like truck, car and tractor. When we drive a vehicle assembled with sink along the periphery of sensor fields or across fields in special paths, we are using mobile sink to obtain sensed information that we need.

In this paper, we propose a circle-based data dissemination (CBDD) algorithm which aims at increasing energy utilization and prolonging network lifetime. In our approach, sensor nodes are symmetrically scattered in a circle sensor field and the mobile sink moves around this circle instead of moving inside it. Information gathering process begins when the sink transmits a query message to one node in the circle area. During the process, all the nodes form different layers according to the distance to sink, then the queried node on inner layer sends data packets to a node on outer layer, finally, sink obtains target information from node on the outmost layer. As the deployment of nodes is symmetrical, when mobile sink moves, the number of nodes near to sink is dramatically increased than that in WSNs with randomly deployed senor nodes and static sink. Consequently, we relieve hot spot issue so effectively that the energy dissipation is evenly distributed in the whole network and the network lifetime is prolonged.

2. Related Work

There are two categories of the motion of sink. One is that sink moves randomly in sensor fields without predetermined paths [7], the other is in the opposite side [8]. In [7], sink can be found in different places where the sojourn time of sink is changeable. In [8], city buses equipped with sink run along the pre-specified traffic routes and gather information from the sensor nodes deployed in urban area near public transportation vehicle routes.

Authors in [9] suggest two solutions to issues related to when, where and how to relocate the sink for network under unconstrained and constrained network traffic respectively. In the former, if total transmission power for nodes that are one-hop away from sink is reduced more than a threshold and overhead of moving sink is tolerable, sink can relocate itself. In the latter, when the average rate of deadline misses for real-time packets starts to increase, sink pursues finding a new position to maintain the same or even better level of timeliness. Both of the approaches can split incoming traffic load of hot spots which helps extending network lifetime. But when under constrained traffic, if some of the last hop nodes increase their transmission range or routes are extended through additional forwarding, the average energy per packet will be a little high.

In [10], the authors propose a framework to maximize the lifetime of the WSNs by using a mobile sink. It formulates optimization problems that maximize the lifetime of the WSN subject to the delay bound constraints, node energy constraints, and flow conservation constraints. However, it assumes that the mobile sink can arrive any location in sensor fields. Actually, it is not possible in most applications and is different from the scenario in our work.

Sometimes the mobile sink chooses some special nodes to be the transit points to receive data packets in the network instead of receiving them directly. Authors in [11] propose a moving pattern called footprint chaining in WSNs with the ZigBee suite of protocols. It means the combination of limited and full address broadcast. While moving through the network the sink ‘footprints’ certain cells and their respective nodes as anchor nodes. For a period of time, each of anchor nodes resumes the role of the sink’s route proxy to (re)detect all misrouted data-readings to the appropriate sink address. Another intelligent agent-based routing structure for mobile sinks in WSNs is proposed in [12] and a protocol named IAR appears of which the idea is choosing some sensor nodes as agents. Then the sink moves near an agent and receives data if it is in the range of the agent, and if not, the sink chooses a node as temporary relay node which receives data from agent and forwards it to sink. This approach is based-on large and densely deployed WSNs and the sink can move in the sensor fields, so it is not appropriate in our network model.

Reference [13] poses four mobility patterns combined with three data collection strategies for mobile sink in WSNs with single mobile sink and each approach achieves different tradeoffs mostly between energy dissipation and time efficiency. It also concludes that the best approach is to follow a fixed trajectory with multi-hop data propagation which is consistent with our work. But the scenario it discussed is common situation and does not consider the special distribution of the network. In our work, we use circle shape distributed network and achieve more satisfactory effect. In [14], authors consider that sensor nodes are deployed in a circle and mobile sink can gather data packets from one ring in the circular region, which is similar to our work.

3. Proposed CBDD Algorithm

3.1 Assumptions

We consider the WSNs using our proposed self-organized CBDD algorithm have some features listed below.

(1) The mobile sink moves around the sensor field and we deem it has infinite power.

(2) The mobile sink can adjust its radio coverage range.

(3) Sensor nodes are deployed in uniform distribution in a circle shape. This guarantees that number of periphery sensor nodes is more than that of inner annulus nodes.

(4) Every sensor node has a fixed ID.

3.2 Network Model

Figure 1 shows the network model which supports our work. Black round dots refer to sensor nodes which are deployed in the circle gray sensor field in uniform distribution. Black triangle stands for the mobile sink. The mobile sink can and only can move along the edge of the circle sensor field. And its motion is bi-directional and free. Due to the uniform distribution of sensor nodes, the nodes in the outer annulus are more than that in inner annulus. To start a query, the mobile sink sends a query order to a specified sensor node, and then this sensor node disseminates its result to the nearest outer sensor node via multi hops. At last, the mobile sink moves to the outer sensor node and retrieves the result.

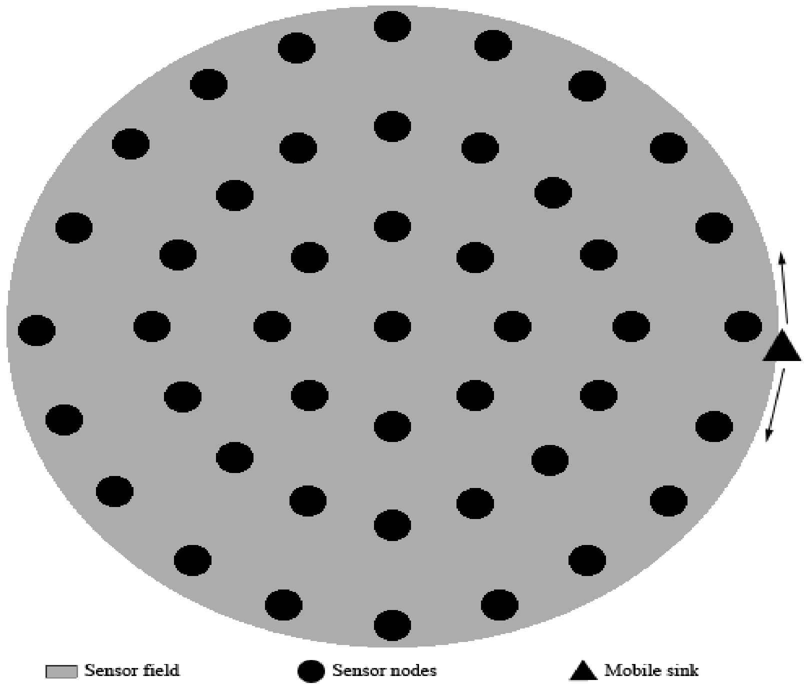

Figure 1. Network Model

3.3 Description of CBDD

In traditional WSNs, resource-constrained sensor nodes are limited in radio range and they communicate with each other via multi hops. Common protocols and algorithms suffer hotspot issue badly. In our algorithm, we call nodes that communicate with sink directly “Direct Transmission” (DT) nodes. DT nodes have to send their own sensed data and forward data packets on the behalf of other nodes. The number of DT nodes is much less than that of other nodes (see Figure 2 (a)), so they will be overused when many data packets surge up to them. The DT nodes die so early that network lifetime gets shorter. To deal with this problem, as shown in Figure 2 (b), we propose CBDD algorithm with mobile sink technology in which the number of DT nodes in our algorithm increases drastically, as a result, the bad hotspot issue is avoided effectively.

Our CBDD algorithm is adopted in query WSNs in which all the nodes keep leisure until it accepts query command from sink. This mechanism is highly self-organized and sensor nodes can find the most suitable route in different data gathering process. Each data gathering procedure can be seen as a round during which sensor nodes with fixed radio coverage range find its father or child nodes to accomplish the whole data transmission mission. The network lifetime is composed of a quantity of rounds and each round has two phases, namely path construction phase and stable data dissemination phase.

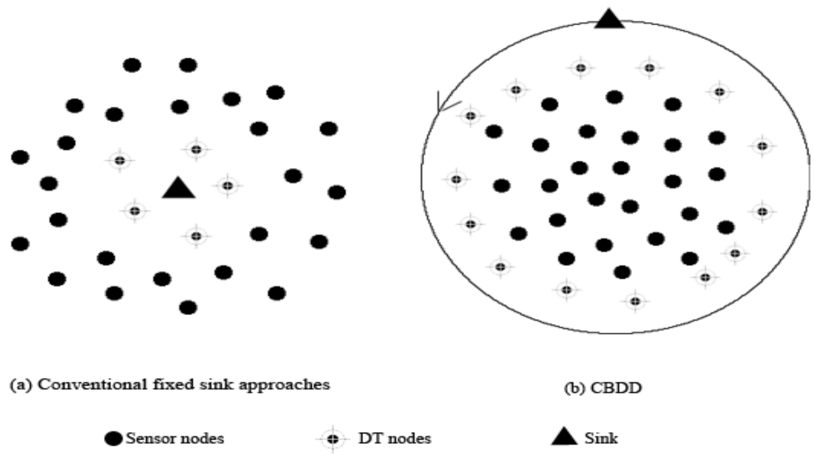

Figure 2. Comparison between Conventional Fixed Sink Approaches and CBDD

(1) Phase 1: path construction

The path construction process begins when all nodes are deployed. Each node has to find its next hop during this procedure. The procedure can be divided into many familiar steps. First, nodes that can communicate with sink by single hop should be settled down as "Layer 1" nodes. It's easy to accomplish the first step because mobile sink can move along the periphery of circle field, as Figure 3 shows. We use R_{ms} denotes for the radio range of the mobile sink.

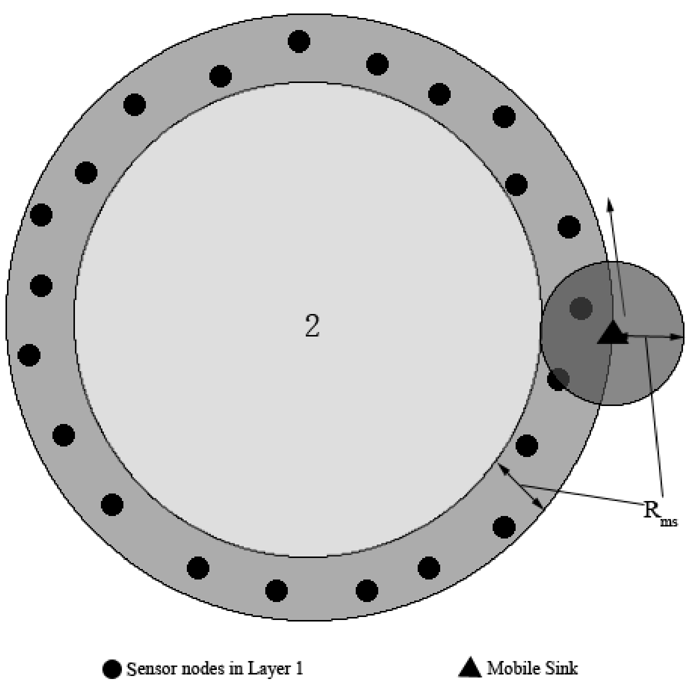

Figure 3. Construction of Layer 1

The second step is to find next hop for nodes in area 2, as shown in Figure 3. In the first step in phase 1, every node in Layer 1 broadcast a FINDCHILD message containing their ID. Nodes in area 2 may receive several FINDCHILD messages, then it chooses the one with the most high signal strength and resolves it to get the ID field in it, then set node which this ID stands for as next hop.

This choice can be conducted by formula (1) below in which l refers to the count of received FINDCHILD messages and $H(i,j)$ refers to the signal strength received by node i and transmitted by node j.

$$\begin{aligned} &Next(i) = k \\ &s.t.\ \ H(i,k) = Max\{H(i,1), H(i,2) \cdots H(i,l)\}, 1 \le k \le l \end{aligned} \tag{1}$$

For instance, as shown in Figure 4, node A, B are nodes in Layer 1, both node A and B broadcast FINDCHILD message and node C out of Layer 1 receives them. After a comparison between these two messages, it choose node A as its father node as the strength of signal from A wins.

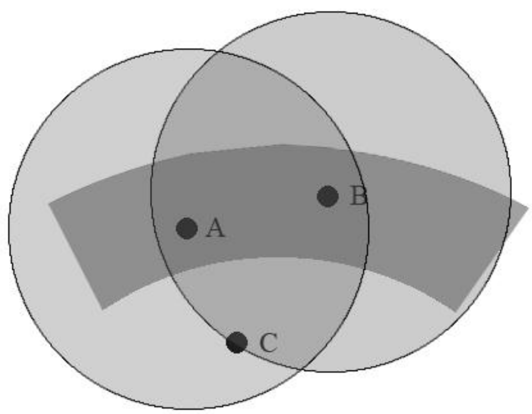

Figure 4. Deciding Next Hop for Node C

After second step is accomplished, we regard the new set of nodes which can be accessed directly by nodes in Layer 1 as Layer 2. By rotating this step, we can build transmission path for each node.

(2) Phase 2: data dissemination

In terms of time, compared with phase 1, phase 2 is longer and more stable. This phase can be divided into three steps listed as follows.

Step 1. The mobile sink broadcasts a query order message to whole sensor field to tell the specified node to return sensed data.

Step 2. The node queried by sink transmits its data packet to node (denoted by SS) in Layer 1.

Step 3. The mobile sink moves to node SS and retrieves the data packets.

Figure 5 shows us this procedure. Although we suppose mobile sink has unlimited energy, we should cut down the total number of circular motion for mobile sink from the perspective of saving earth's resources. To achieve this purpose, we regulate that when and only when one node is queried twice, the sink will move around the circle area again and get all data packets from the outmost nodes.

During the network lifetime, some nodes may deplete their energy earlier than others, obviously it should be abandoned by the system due to its death. However, what should catch our attention is that if next hop of one node dies and this node can't find other routes to nodes on the outmost layer, it will be deemed abandoned too.

As shown in Figure 5, if node D dies, node A, B, C cannot contribute to end users anymore and they are abandoned. For computing the communication load of one node, we conclude it as formula (2). *set(i)* refers to the set of nodes whose next hop is node i and m means that there are m nodes in *set(i)*.

$$Load(i) = \sum_{k=1}^{k=m} load(k); m = |set(i)| \quad (2)$$

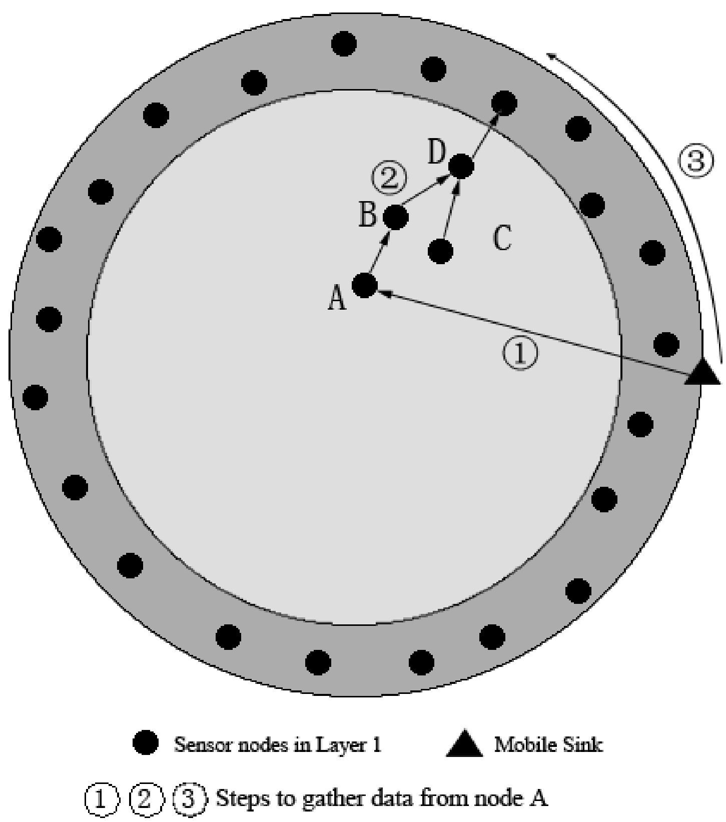

Figure 5. Procedure of Gathering Data from Nodes

4. Performance Evaluation

4.1 Energy Model

In our work, we use the classical radio model and characteristics proposed by reference [1]. We assume sensed data packet is always k bits in length. Due to the fixed radio coverage range (denoted by R_{sn}), energy cost for a node to transmit a packet can be computed by formula (3) and energy cost for a node to forward a packet can be computed by formula (4). In these two formulas, E_{t-elec} and E_{r-elec} represent respectively the energy that radio dissipates to run the transmitter and receiver circuitry. Radio consumes $\varepsilon_{amp} = 0.1nJ / bit / m^2$ for transmit amplifier.

$$E_{transmit} = E_{t-elec} \times k + \varepsilon_{amp} \times k \times R_{sn}^2 \quad (3)$$

$$E_{forward} = E_{r-elec} \times k + E_{t-elec} \times k + \varepsilon_{amp} \times k \times R_{sn}^2 \quad (4)$$

Several variables aforementioned were listed in Table 1 as in [1].

Table 1. Default Values of Variables

Name	Value
E_{t-elec}	50 nJ/bit
E_{r-elec}	50 nJ/bit
ε_{amp}	0.1 nJ/bit/m^2
k	2000 bits

4.2 Simulation Study

Because radio coverage of sensor nodes is limited and if one node losses its link to the outer nodes, it cannot contribute to the end users any more, and its residual energy is wasted. In these scenarios, we pose to use the energy utilization γ as a criterion to judge if a protocol or algorithm is energy efficient. Suppose there are N nodes in our system, N_{con} is the module of contributive nodes set. Contributive nodes refer to those nodes have link to disseminate their sensed data to end users in each round. The initial energy of each node is $E_{initial}$, $E_{\cos t}$ represents the energy dissipated in each round and $E_{total\_\cos t}$ stands for total energy cost from the first round to the present one. $E_{\cos t}$, $E_{total\_\cos t}$ and γ in round i can be calculated as:

$$E_{cost}(i) = \sum_{j=1}^{N_{con}} (n_{packet}(j) - 1) \times E_{forward} + E_{transmit} \quad (5)$$

$$E_{total\_\cos t}(i) = \sum_{m=1}^{i} E_{\cos t}(m) \quad (6)$$

$$\gamma = \frac{E_{total\_cost}(i)}{E_{initial} \times N} \quad (7)$$

where $n_{packet}(j)$ is the total number of data packets to transmit at node j consisted of its own packet and packets from its children.

The simulation results prove that novel CBDD algorithm we present outperforms the conventional Data Dissemination approaches which use a Fixed Sink (FSDD) in terms of energy utilization and prolonging network lifetime.

We simulate CBDD algorithm based on the network shown in Figure 6 in which sensor nodes are deployed in the circle with radius equals to 100 and center is at point (100, 100). In Figure 6, the round dots refer to regularly deployed sensor nodes and distribution of them is uniform.

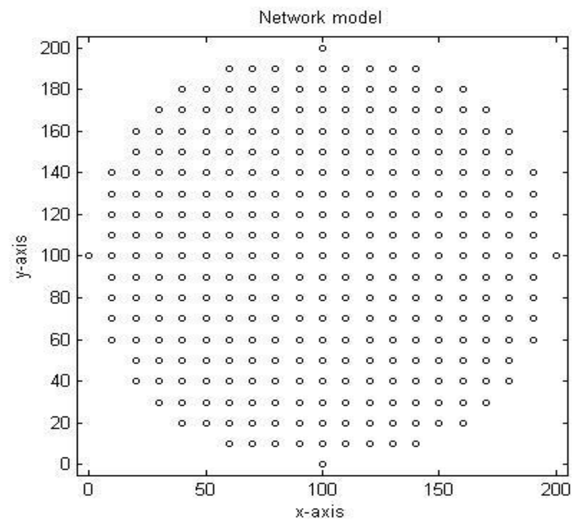

Figure 6. Network Model

As shown in Figure 7, CBDD algorithm achieves better energy utilization than FSDD. Energy utilization can be obtained with formula (6). Final energy utilization of CBDD and FSDD are 71.72%, 16.55% respectively. The primary cause of low energy utilization of the conventional is that hotspot issue occurred on DT nodes, and then those nodes die early and other nodes cannot communicate with sink any more. These nodes are abandoned even though their residual energy is plenteous, which further causes the waste of energy. From Figure 7 we can also watch that the speed of energy consumption of FSDD is faster than that of CBDD.

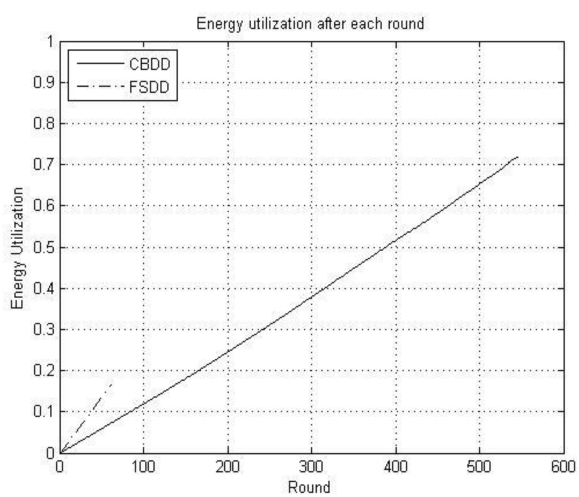

Figure 7. Energy Utilization in Each Round

We define the network lifetime as the time when half of nodes disable. A node disables when it has no residual energy. Figure 8 shows us the comparison of number of contributive nodes between CBDD and FSDD. Network lifetime using CBDD and FSDD are 545, 61 rounds respectively. As aforementioned, we consider those nodes that lose link with outer nodes are disabled because of their zero contribution. In FSDD, hotspot phenomenon disables the network early, but in CBDD, outer DT nodes are much more than inner nodes, therefore avoiding DT nodes to be hot nodes.

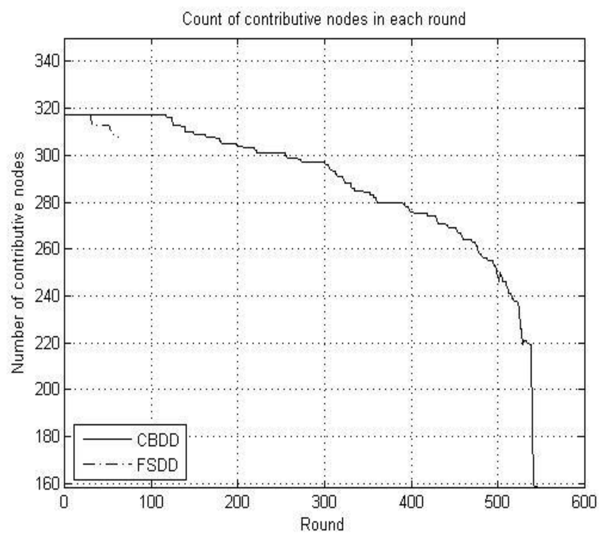

Figure 8. Number of Contributive Nodes in Each Round

5. Conclusions

In this paper, a novel data dissemination algorithm called CBDD is proposed which is operated in WSNs with radio-range-limited sensor nodes and single mobile sink. In our CBDD mechanism, sensor nodes are supposed to be uniformly deployed in a circle sensor field. The mobile sink always moves along the periphery of the circle area and retrieves data packets from nodes on outer layer in this field. The presented results demonstrate that our CBDD mechanism is better than former algorithms based on WSNs with asymmetrically deployed nodes and single static sink in terms of reducing energy dissipation and prolonging network lifetime. It dramatically increases the number of DT nodes and avoids the hot spot issue effectively. Our CBDD algorithm is used for query-based WSNs. The future extension of the current work is that we will study the utilization of network structure of CBDD mechanism in periodic-based WSNs.

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