TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.2, February 2014, pp. 1424 ~ 1430
DOI: http://dx.doi.org/10.11591/telkomnika.v12i2.3736

Multi-track Mobile Data Collection Mechanism for Wireless Sensor Networks

Lei Fu*[1], Guoqiang Zheng[1], Jishun Li[2]
[1]School of Electronic Information Engineering, Henan University of Science and Technology, Luoyang 471003, China
[2]Henan Key Laboratory for Machinery Design and Transmission System, Henan University of Science and Technology, Luoyang 471003, China
*****Corresponding author, e-mail: fuleifox@gmail.com

Abstract

Wireless sensor networks (WSNs) have been widely researched by countries and institutes. The limited node energy has already become a constraint of large-scale applications. Seeking the energy-balance features at sensor nodes to prolong the network lifetime, a multi-track mobile data collecting mechanism (MTMDC) was proposed in this paper. The MTMDC mechanism was composed of three major phases: the Nodes Estimation Phase, the Energy Estimation Phase and the Multi-track Energy-balance Phase. Based on the three phases, a data collection path for mobile data collector or mobile sink (MS) was built to balance the energy consume of the sensor nodes. Theoretical analysis and performance simulations indicated that the proposed MTMDC mechanism has prominent features compared with the existing approaches in terms of the energy-balance performance and network lifetime.

Keywords*: wireless sensor networks, multi-track, energy-balance, mobile data collection, network lifetime*

1. Introduction

WSNs have been widely used in target tracking, environmental monitoring, industrial and agricultural managing [1]. Recent studies prove that great benefit can be achieved for data collection in WSNs by employing mobile data collectors [2-3]. The bottleneck problem of the traditional static sink mechanism is deeply solved by this employment [4-6]. The optimal energy-saving way is letting MS traverse each node [7], but the relatively low speed of MS will result in long time delay in the data collection process. These solutions tend to be restricted in some delay sensitive applications.

The hybrid mechanisms of mobility and data relay have frequently been proposed in recent years. Chu at el [8] proposed a heterogeneous data distribution mechanism that MS concentrates data collection on some specific nodes to optimize the network energy consumption. Lin et al [9] raised a cluster-based data collection mechanism to solve the buffer overflow problems in which MS collects data from the clusters. However, the above papers fail to employ the energy-balance mechanism to improve the network performance.

For the view of the network energy-balance problem and data collection delay, the MTMDC mechanism is proposed in this paper. One MS is used in MTMDC and it is made to move along the defined energy-balance path to collect data. The MTMDC mechanism proposed in this paper is applicable to various applications, especially in environmental monitoring, weather monitoring and other periodic non real-time monitoring applications. Simulation results show that MTMDC has great advantages on energy-balance performance and practicability.

2. MTMDC Mechanism

The MTMDC mechanism has a wide rang of applications. The data collection path of MS can be defined by MTMDC in most terrains. Pursuing with the simple description and expandability, a regular hexagon two-dimensional sensing field is chosen as an example.

In the entire WSNs, *N* nodes are randomly and uniformly deployed in the area with a practical density *d*. The distance from the center point to the vertex point is *R*. For saving the

Received June 29, 2013; Revised September 2, 2013; Accepted September 21, 2013

cost of actual applications, the communication radiuses of all sensor nodes and MS (or other Mobile data collection devices) are *r*.

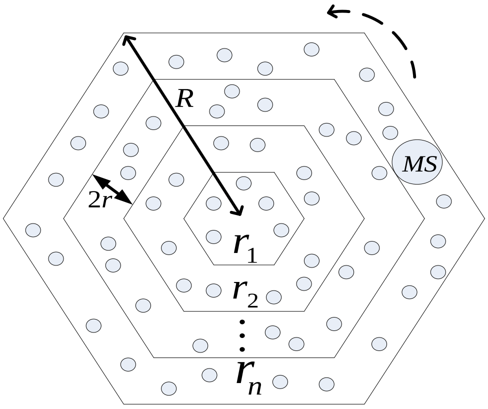

Figure 1. MTMDC System Model

As shown in Figure 1, in order to balance the energy consumption of all sensor nodes, the application region is divided into *n=R/2r* rings by the node communication radius *r*. The width of each ring is *2r*.

MS runs in the middle of each ring to collect data. Assuming that the data upload period of the entire sensing field is t, in order to collect the data generated by all nodes when MS complete one round of movement in any ring, the time consumption of MS in each ring is no more than t. So MS runs with different speed in deferent rings.

Sensors in different rings transmit data to MS in a multi-hop way. To focus the work on building the energy-balance data collection path, the multi-hop routing algorithms [10-11] are used in the mechanism. Therefore, when MS completes the movement for one round in any ring, it can collect the information generated by all nodes in the entire sensing field.

2.1. Nodes Estimation Phase

Assuming that MS moves in ring $r_{collect} = r_i$, all nodes in other rings need to send the generated data in a multi-hop way to their nearest nodes in ring r_i. When MS moves into the communication radius of the nodes, the data is uploaded. Therefore, the relay cost of all nodes in ring r_i can be balanced.

Assuming that $\overline{S}_i'$ is the area of a regular hexagon, the distance from the center point to the vertex point is R_i. $\overline{S}_i$ is the area of ring r_i, and $\overline{S}_i$ is defined by the difference between the two neighbor hexagons:

$$\overline{S}_i = \overline{S}_i' - \overline{S}_{i-1}' = \frac{3\sqrt{3}}{2}\left(r_i^2 - r_{i-1}^2\right) \tag{1}$$

N_i is the number of the nodes in ring r_i. As shown before, the node deployment density is *d*. N_i can be calculated by the area of the ring and the deployment density of the nodes:

$$N_i = d \times \overline{S}_i, 1 \le i \le n \tag{2}$$

2.2. Energy Estimation Phase

The energy consumption of each node is evaluated in this phase. Let e_{ij} indicate the average energy consumption of a node in ring r_i when MS has completed one round of movement in ring r_j. E_{ij} is the total energy consumption of all nodes in ring r_i. e_{ij} is given as an average value by the ratio of E_{ij} and N_i. Based on the geographical positions, e_{ij} can be defined into three categories as follows:

Table 1. Average Energy Consumption of A Node In Each Time Period

Category	*Energy Consumption (e_{ij})*
I	$e_{ij}^{in} = \frac{\sum_{k=1}^{i} \lvert S_k \rvert \times q}{N_i}$
II	$e_{ij}^{out} = \frac{\sum_{k=i}^{n} \lvert S_k \rvert \times q}{N_i}$
III	$e_{ij}^{equal} = \frac{\sum_{k=1}^{n} \lvert S_k \rvert \times q}{N_i}$

Proofs:

The first category is used as an example. Ring r_i is inner from the center of the sensing field than ring r_j. The categories are different from each other by the different relay ranges. While r_i is outer than r_j, e_{ij} is shown as e_{ij}^{out} and e_{ij} is shown as e_{ij}^{equal} when r_i and r_j are in the same ring.

As described before, e_{ij}^{in} is used to shown the average energy consumption. So e_{ij}^{in} is calculated as follows:

$$e_{ij}^{in} = \frac{E_{ij}^{in}}{N_i} \tag{3}$$

Assuming that D_i is the total amount of data transmitted in ring r_i, e_{unit} is the energy consumption of every unit of data transmission. E_{ij}^{in} is shown as follows:

$$E_{ij}^{in} = D_i \times e_{u\,\mathrm{int}} \tag{4}$$

In actual applications, the data generated by each sensor node in every time period *t* is specific given. The node here is set to generated one packet with the size of *q* in each period. D_i is described as follows:

$$D_i = \sum_{k=1}^{i} \lvert S_k \rvert \times q \tag{5}$$

As shown above, e_{ij}^{in} is specific determined as follows:

$$e_{ij}^{in} = \frac{\sum_{k=1}^{i} |S_k| \times q}{N_i} \tag{6}$$

As shown in formula (6), the average energy consumption e_{ij}^{in} is defined. The relay rings contains all the rings from 1 to *i*. The certification processes of the other two types are basically the same. The relay rings of e_{ij}^{out} is from *i* to *n*, and it is from 1 to *n* for e_{ij}^{equal}.

2.3. Multi-Track Energy-Balance Phase

In this phase, the energy-balance path $T_{MTMDC} = (x_n, x_{n-1}, \cdots x_1)$ of MS is formed by the data calculated above, where x_i is the number of rounds that MS travels in ring r_i. So MS runs ring by ring with different rounds in the sensing field. According to this path, the energy consumption of all nodes can be balanced in the data collection period.

To match most practical applications, MS moves inwardly from the boundary of the application region. MS first runs in ring r_n for x_n rounds and then the inner ring r_{n-1} for x_{n-1} rounds. Finally, after x_1 rounds in ring r_1, the data collection path $T_{MTMDC} = (x_n, x_{n-1}, \cdots x_1)$ is completed for one time.

Assuming that e_i^{total} is the total energy consumption of a random node s_i when MS complete the T_{MTMDC} for one time, s_i is a random node in ring r_i. x_j is value of the moving rounds of MS in the data collection ring r_j. As describe above, e_i^{total} is defined as follows:

$$e_i^{total} = \sum e_{ij} \times x_j \tag{7}$$

As shown in Table 1, the symbol $\sum e_{ij}$ in formula (7) above takes different values when the geographical positions are different.

For the energy-balance purpose of MTMDC, MS conducts the data collection work with the defined path $T_{MTMDC} = (x_n, x_{n-1}, \cdots x_1)$. Any two nodes should have the same energy consumption. Based on the formulas above, the following relationship is given:

$$\begin{bmatrix} e_{11}^{equal} & e_{12}^{out} & \cdots & e_{1n}^{out} \\ e_{21}^{in} & e_{22}^{equal} & \cdots & e_{2n}^{out} \\ \vdots & \vdots & \ddots & \vdots \\ e_{n1}^{in} & e_{n2}^{in} & \cdots & e_{nn}^{equal} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} e_1^{total} \\ e_2^{total} \\ \vdots \\ e_n^{total} \end{bmatrix} = \begin{bmatrix} e_1^{total} \\ e_1^{total} \\ \vdots \\ e_1^{total} \end{bmatrix} \tag{8}$$

Taking the inverse transformation of formula (8), $T_{MTMDC} = (x_n, x_{n-1}, \cdots x_1)$ is described as follows:

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} e_{11}^{equal} & e_{12}^{out} & \cdots & e_{1n}^{out} \\ e_{21}^{in} & e_{22}^{equal} & \cdots & e_{2n}^{out} \\ \vdots & \vdots & \ddots & \vdots \\ e_{n1}^{in} & e_{n2}^{in} & \cdots & e_{nn}^{equal} \end{bmatrix}^{-1} \begin{bmatrix} e_1^{total} \\ e_1^{total} \\ \vdots \\ e_1^{total} \end{bmatrix} \tag{9}$$

When the results are not integers, the nearest integer values are chosen as the moving rounds of MS. In conclusion, the energy balance data collection path $T_{MTMDC} = (x_n, x_{n-1}, \cdots x_1)$ of MS is formed by the three phases above.

In practical data collection, MS calculates the running rounds, the starting time and the start point and then conducts the data collection task. In summary, the energy consumption of the nodes in any rings can be balanced when MS completed one round in the ring and the energy consumption of all nodes can be balanced when T_{MTMDC} is completed for one time.

3. Results and Analysis

In this part, simulations are used to evaluate the performance of the proposed MTMDC mechanism. Inspired by the MS moving path of EDGS [9], we compare MTMDC with the existing static sink mechanisms classified as STATIC in [4-6] and the mobile sink mechanisms classified as EDGS in [7-9].

In the simulations, the network scale *R* is 300m, the number of nodes ranges from 50 to 150. The data upload period ranges from 3 hours to 11 hours. The inicial energy of each node is 1000J. The energy consumption of packet transmission is 0.070J/s, the energy consumption of packet reception is 0.070J/s and the idle cost is 0.020J/s. The figures following are drawn by the mean value from simulations in the same environment.

Figure 2 and Figure 3 show the comparison of the three mechanisms on the network lifetime performance. The network lifetime is defined by the time duration from the beginning of the network to the time the first monitoring hole appears. We here use the number of nodes and the data upload period as the variables, the results are shown in Figure 2 and Figure 3.

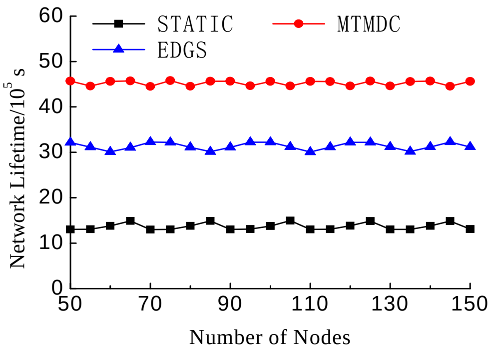

Figure 2. Comparation with the Number of Nodes

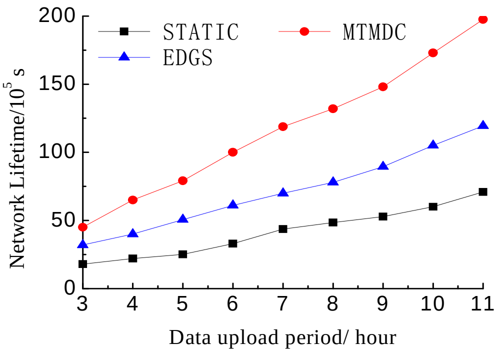

Figure 3. Comparation with the Data Upload Period

As shown in Figure 2, in the STATIC mechanism the network lifetime decreases dramatically with the increase of the number of nodes. Because the sink node or the base station is located in the center position, the bottleneck effect will be exacerbated with the network scale and results in a significant lifetime decrease. The IDGP mechanism optimizes the data upload hops to reduce the data relay consumption. It relatively extends the lifetime of the network. Compared with the two mechanisms, the MTMDC mechanism which adopts the energy-balance data collection path significantly improved the network lifetime.

Figure 2 shows the comparison of the three mechanisms on the network lifetime performance with different data upload period. The data upload period is defined by actual applications.

As shown in Figure 3, the network lifetime increases linearly with the increase of the data upload period. Because the data relay frequency is reduced by the increased data upload period. Thereby, the energy consumption of nodes is reduced and the network lifetime is prolonged. For the use of the energy-balance path, MTMDC has a clear superiority on the network lifetime.

As shown in Figure 4, the energy-balance performance is compared. A center node and a boundary node are randomly selected. The difference of the average energy consumption is compared between the selected nodes. The difference between the average energy consumption of the node in every unit time is selected as the evaluation object. In order to improve the veracity and the comparability, the boundary nodes and the center nodes are selected as an example.

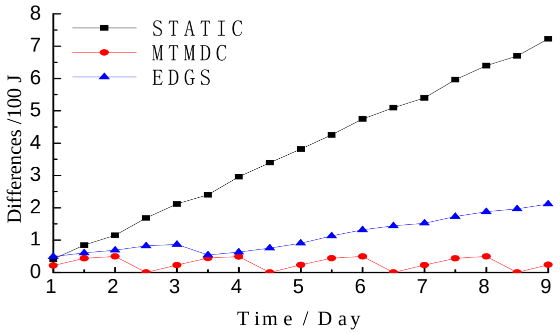

Figure 4. Differences of the Average Energy Consumption

As shown in Figure 4, because of the bottleneck effect, the differences between the center node and the boundary node increase with the operation of the network in the STATIC mechanism. In EDGS, although the path planning and the hops limiting algorithms are used to reduce the total energy consumption, the deference of the energy consumption between the center node and the boundary node still increases in a relatively lower speed. However, for the use of the energy-balance data collection path T_{MTMDC} , MTMDC appears perfect on the energy-balance performance. The deference of the energy consumption periodically comes to zero. Moreover, the proposed MTMDC mechanism obviously outperforms other data collection mechanisms on the comprehensive performance.

4. Conclusion

Based on the energy-balance performance and the practicability performance, a multi-track large-scale mobile data collection mechanism (MTMDC) is proposed in this paper. MTMDC can determine the energy-balance data collection path of MS and the data collection strategy. The energy consumption of the entire network can be balanced and the network lifetime can be prolonged. MTMDC is an efficient and practical data collection mechanism and has outstanding features on the practicability and energy-balance performance.

Acknowledgements

This research is supported by the National Hi-Tech Research Development Program (863 Program) (no. 2009AA044902), Major national science and technology projects (2012ZX04004011), Henan Province basic and frontier technology research project (122300413209), the Henan University of Science and Technology Scientific Research Start-up Foundation for Dr. (NO. 09001550), the Education Department of Henan province science and technology research project (12B510010)

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