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Lifetime Optimized Power-saving Data-gathering Algorithms for Wireless Sensor Networks

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Abstract: In some power-saving data-gathering algorithms, some hub nodes take too much data packet forwarding. It leads to premature depletion of node power and even be death. Those gathering algorithms reduce the entire network energy consumption but shorten the network lifetime. To solve the problem, energy for transmitting data between network nodes, residual energy of own nodes, residual energy of neighbor nodes and the data-gathering minimum routing hop are comprehensively considered. Dijkstra algorithm is used and two weight functions are introduced. Then ratio weight gathering algorithm and sum weight gathering algorithm are proposed. Simulation results show that the two algorithms can prolong network lifetime, reduce network latency and enable cost-effective energy consumption. Under certain conditions, the two algorithms outperform Power Efficient Data-gathering and Aggregation Protocol (PEDAP), Power Efficient Data-gathering and Aggregation Protocol-Power Aware (PEDAP-PA) and Least Energy Tree (LET).

Key words: Wireless sensor network, data gathering, network lifetime, lifetime optimized, network, latency

INTRODUCTION

One of the non-standard metrics of interest is the network lifetime to maximize. First, this is specially intended for battery-powered networks such as a WSN. Second, there has been no unified definition of the term “lifetime” for such a network (Xu and Cassandras, 2009). As depletion of one node’s energy will affect the normal application of wireless sensor networks, network lifetime can be defined as the time from network beginning to one node running out of energy (Wang and Howitt, 2005).

Related researches have got some accomplishments. To minimize the total energy consumption, the data-gathering algorithms have been studied (Heinzelman *et al*., 2000; Kalpakis *et al*., 2003; Lindsey and Raghavendra, 2002). Tan and Korpeoglu (2003) proposes PEDAP and PEDAP-PA. They are based on minimum spanning tree routing protocol. Link weight is defined and minimum spanning trees are constructed by PRIM algorithm. Data finally aggregate to sink node along minimum spanning trees. Zhu *et al*. (2009) proposes LET algorithm. LET is based on Dijkstra algorithm to minimize the energy consumption from each node to sink node. But neither of those algorithms considers neighbor nodes’ residual energy or nodes’ minimum hops. Their efforts on prolonging network lifetime are not particularly good. Therefore, in order to overcome the deficiencies of above algorithms and prolong network lifetime, this study develops the research accomplishment mentioned (Zhu *et al*., 2009) and proposes Ratio Weight Gathering Algorithm (RWGA) and Sum Weight Gathering Algorithm (SWGA). The algorithms research on new weight functions based on energy consumption, residual energy, minimum hops and use the shortest path tree algorithm (Dijkstra) to construct the shortest path. Each sensor node transmits data to sink node along its shortest path.

ENERGY CONSUMPTION MODEL OF DATA-GATHERING

The energy consumption of transmission node contains the electronic energy consumption of transmission circuit and signal amplifier. The energy consumption of transmission circuit is kE_{elec}, where, k represents the amount of transmitted data. Energy consumption of signal amplifier relates to the transmission distance d. When, the distance is longer than maximum transmission distance d_{max}, the nodes can not

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communicate. Its Energy consumption is infinite. When the distance is larger than crossover distance $d_{crossover}$ and less than d_{max}, the energy consumption chooses multipath fading model. When the distance is less than $d_{crossover}$, it chooses Friis free space model. Energy consumption of receiver node only considers the electronic energy consumption kE_{elec} (Wang *et al*., 2010). Therefore, energy consumption of k-bits data transmission between node i and node j is:

$$C_{i,j}(k)=\begin{cases}2kE_{elec}+k\varepsilon_{friss\text{-}amp}(d)^2 & d<d_{crossover}\\ 2kE_{elec}+k\varepsilon_{two\text{-}ray\text{-}amp}(d)^4 & d_{max}\geq d\geq d_{crossover}\\ \infty & d\geq d_{max}\end{cases} \quad (1)$$

The energy consumption between node i and sink node is (Chen *et al*., 2010):

$$C_{i,s}(k)=\begin{cases}kE_{elec}+k\varepsilon_{friss\text{-}amp}(d)^2 & d<d_{crossover}\\ kE_{elec}+k\varepsilon_{two\text{-}ray\text{-}amp}(d)^4 & d_{max}\geq d\geq d_{crossover}\\ \infty & d\geq d_{max}\end{cases} \quad (2)$$

Where:

$d_{crossover}$ = 86.2 m
E_{elec} = 50 nJ bit^{-1}
$\varepsilon_{friis\text{-}amp}$ = 100 pJ bit^{-1} m^{-2}
$\varepsilon_{two\text{-}ray\text{-}amp}$ = 0.0013 pJ bit^{-1} m^{-4}

LIFETIME OPTIMIZED POWER-SAVING DATA-GATHERING ALGORITHMS

Besides the link weight energy consumption (1, 2), the residual energy of nodes themselves, the residual energy and minimum hops of neighbor nodes are taken into account. New link weight functions are introduced. Ratio Weight Gathering Algorithm (RWGA) and Sum Weight Gathering Algorithm (SWGA) are proposed.

In RWGA:

$$w_{ij}=\left[C_{ij}(k,d_{ij})\right]^{\alpha}\left[\frac{1}{Re(i)}\right]^{\beta}\left[\frac{1}{Re(j)}\right]^{\gamma}[Hop(i,j)]^{\theta} \quad (3)$$

where, α, β, γ, θ are positive parameters and called link energy consumption factor, residual energy factor of transmission node, residual energy factor of receiver node and hop factor separately.

In SWGA:

$$w_{ij}=\lambda C_{ij}(k,d_{ij})+\delta\frac{1}{Re(i)}+\mu\frac{1}{Re(j)}+\varepsilon Hop(i,j) \quad (4)$$

where, λ, δ, μ, ε are positive parameters and $\lambda+\delta+\mu+\varepsilon = 1$. They are called link energy consumption weight, residual energy weight of transmission node, residual energy weight of transmission node, hop weight separately. It is concluded that when $\alpha = 1$, $\beta = 0$, $\gamma = 0$, $\theta = 0$ and $\lambda = 1$, $\delta = 0$, $\mu = 0$, $\varepsilon = 0$, RWGA and SWGA will both turn out to LET.

System assumptions: Assume that:

- Sink node and other nodes are static with fixed location. Moreover, sink node has the topology information of whole network
- Ordinary nodes have the same performance (such as initial energy, energy consumption parameters, radio transmission power, communication radius)
- Ordinary nodes have the same energy model
- Sink node gathers data regularly and ordinary nodes transmit data to sink node directly or in multi-hop way
- Each ordinary node's energy is limited and sink node's energy is not limited

Realization of RWGA and SWGA: RWGA and SWGA are two kind of centralized data-gathering algorithms. The implementation of the algorithms is mainly completed in the sink node. Once network starts, sink node begins to gather data. First, sink node transmits information query packets to other nodes in flooding way. When nodes receive the packet from sink node, they record the minimum hops from neighbor node to sink node and add 1 automatically as its hops. Meanwhile, nodes transmit information to sink node through the same path. The information contains their node locations, residual energy Re(i), the amount of transmission data, minimum hops of the chosen path and so on. Then, after sink node receives information, RWGA (or SWGA) starts to calculate the optimal data-gathering path of each node. Then sink node floods the information of the optimal data-gathering path to any other nodes. All nodes transmit data along the received path. Finally, after a certain time interval, sink node transmits information query packets, updates the topology information of whole network and calculates optimal path again.

According to the mentioned assumption, it is concluded that after sink node have known the location of all nodes and completed information query, it will get residual energy Re(i) of all nodes, amount k of data node needs to transmit and hops of neighbor node to sink node. Then, the weight is calculated with Eq. 3 and 4. RWGA and SWGA can be realized in sink node.

The pseudo code of RWGA and SWGA is as follows:

- Initialization phase (Sink node gathers the information of nodes such as the locations, residual energy Re(i), the amount of transmission data, minimum hops)
- While ($Re(i)>0$, $i\in V$)

Table 1: Simulation parameters

Parameters	Value
Electronic energy consumption for transmitting and receiving data E_{elec}	50 nJ bit^{-1}
Energy consumption for amplifying signal in Friis free space model $\varepsilon_{friis\text{-}amp}$	100 pJ bit^{-1} m^{-2}
Energy consumption for amplifying signal in multipath fading model $\varepsilon_{two\text{-}ray\text{-}amp}$	0.0013 pJ bit^{-1} m^{-4}
Node's communication radius d_{max}	200 m
Cross over distance $d_{crossover}$	86.2 m
Square's side length in network area L	500 m
Node's initial energy E	1000 J
Data size transmitting to sink node every time	1 kb
Weight update interval of network (times of node transmission before update)	1000

- All w_{ij}, $i \in V$, $j \in N(i)$ are calculated according the formula (3) or (4)
- Dijkstra algorithm is used to construct the shortest path
- Each sensor node transmits data to sink node along its shortest path
- $Re(i)=Re(i)-\sum_{j\in N(i)} C_{ij}(k,d_{ij}), i\in V;$
- Sink node gathers the information of nodes' residual energy; End if

where, V represents the set of nodes, N(i) represents all neighbor nodes set of node i.

Simulation and experiment: The simulation doesn't consider the energy consumption of routing establishment, routing maintenance, routing failure, timeout retransmission, data calculation and some others but only consider the energy consumption of wireless communication. As shown in Table 1, 500×500 m^2 network simulation area is chosen. 25, 30, 35, 40, 45 and 50 nodes are randomly generated. About 10 different network topologies are randomly generated. Then the network lifetime, average energy consumption and latency time of data-gathering algorithms are given.

In the simulation, Data Gathering Cycle (DGC) represents the network lifetime. DGC is the time that all nodes successfully transmit data to sink node:

$$\text{Average network latency} = \frac{\text{The total number of hops all nodes need to transmit}}{\text{DGC} \times \text{number of nodes}}$$

$$\text{Average energy consumption} = \frac{\text{The total number of energy all nodes consume}}{\text{DGC} \times \text{number of nodes}}$$

RWGA ALGORITHM

Selection of α: When β = 1, Y = 1, θ = 1 and α≥1 α = 1, 3, 5, 7, 9 are chosen in network with 25, 30, 35, 40, 45 and 50 nodes. As shown in Fig. 1, it is concluded that when α increases, network lifetime will shorten.

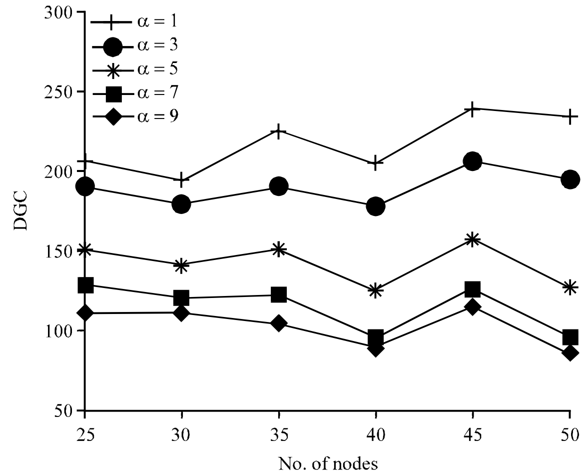

Fig. 1: Network lifetime (DGC) when α≥1

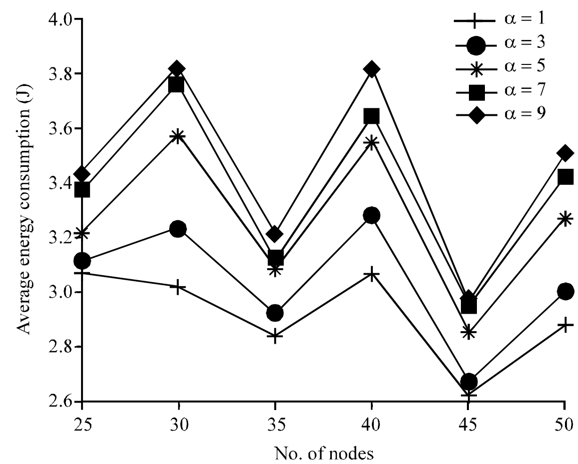

Fig. 2: Average energy consumption when α≥1

As shown in Fig. 2, it is concluded that when α increases, average network energy consumption will increase.

It is reason that when α≥1 and α increases, the effect of link energy consumption in Eq. 3 enhances while the effect of node residual energy, neighbor residual energy and minimum hops weakens. Thus, the network lifetime shortens and energy consumption increases. In addition, when α<1, the larger α is (more close to 1), the longer network lifetime is and the lower average network energy consumption is. It is reason that when α<1, the effect of link energy consumption in Eq. 3 weakens. Therefore, the nodes with more residual energy will transmit data directly to the nodes along the path of less hops and longer distance (the figures of simulation result are omitted here). In summary, choosing the appropriate α (α = 1), RWGA has longer network lifetime.

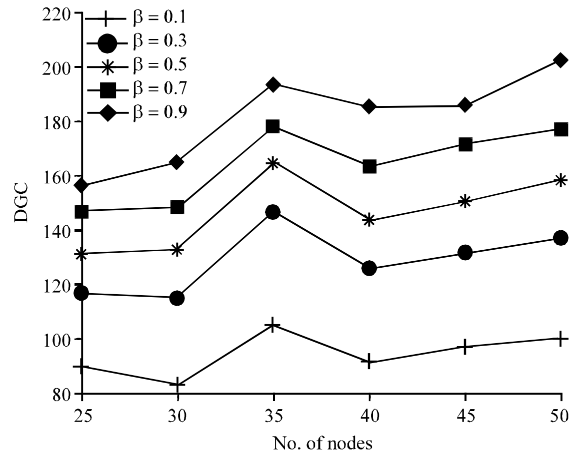

Fig. 3: Network lifetime (DGC) when β<1

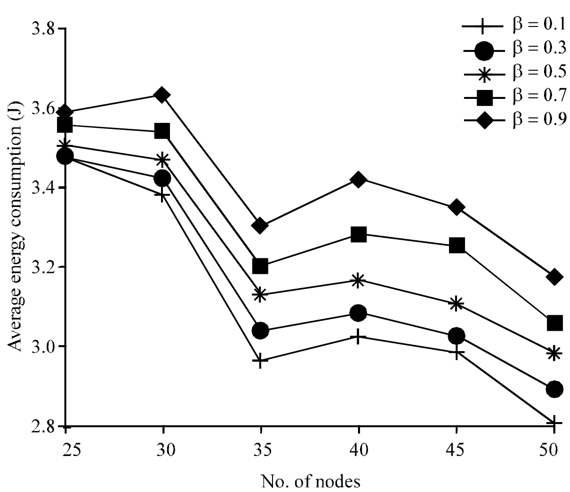

Fig. 4: Average energy consumption when β<1

Selection of β: When $\alpha = 1$, $\Upsilon = 1$, $\theta = 1$ and $\beta<1$, $\beta = 0.1, 0.3, 0.5, 0.7, 0.9$ are chosen. As shown in Fig. 3, it is concluded that the more close to 1 β is, the longer network lifetime is.

As shown in Fig. 4, it is concluded that the more close to 1 β is, the larger energy consumption is.

It is reason that weight function hardly considers the effect of node residual energy, so that some hub nodes take too much data packet forwarding. It leads to premature depletion of node power and even be death. Meanwhile, only part of hub nodes in network cost much energy and others are not. Thus, the average energy consumption of network is smaller. In addition, when $\beta = 1$, the smaller β is, the longer network lifetime is and the lower energy consumption is. It is reason that when $\beta = 1$, the effect of other three parameters weakens. It makes some nodes transmit data directly to the neighbor nodes with higher link energy consumption. That will shorten network lifetime and increase average energy consumption (The figures of simulation result are omitted here). In summary, choosing the appropriate β ($\beta = 1$), RWGA has longer network lifetime.

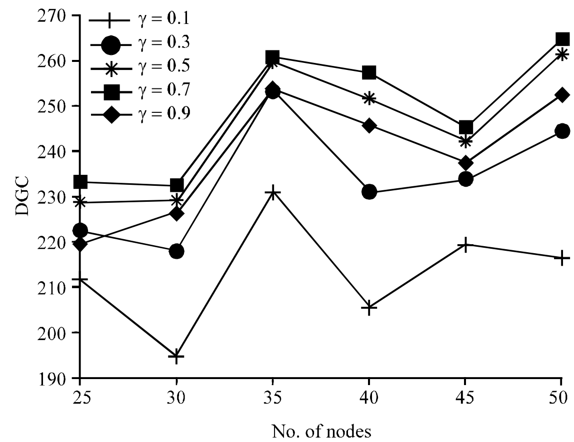

Fig. 5: Network lifetime (DGC) when γ<1

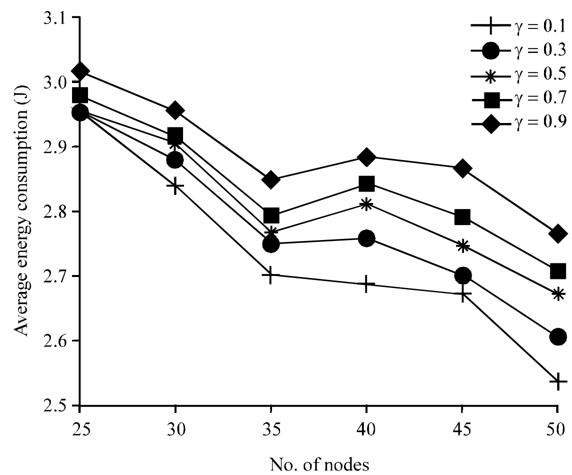

Fig. 6: Average energy consumption when γ<1

Selection of γ: When $\alpha = 1$, $\beta = 1$, $\theta = 1$ and $\gamma<1$, $\gamma = 0.1, 0.3, 0.5, 0.7, 0.9$ are chosen. As shown in Fig. 5, it is concluded that when $\gamma<0.7$, the effect of neighbor residual energy in Eq. 3 weakens. The network lifetime increases as γ increases. However, when $\gamma = 0.7$, network lifetime is comparatively longer. Then, when $\gamma = 0.9$, neighbor node residual energy is over considered and network lifetime shortens.

As shown in Fig. 6, it is concluded that the network energy consumption increases as γ increases. The reason is same as Network lifetime when γ<1.

In addition, when $\gamma = 1$, the simulation result is similar to the result when $\beta = 1$ (the figures of simulation result are omitted here). In summary, choosing the appropriate γ ($\gamma = 0.7$), RWGA has longer network lifetime.

Selection of θ: When $\alpha = 1$, $\beta = 1$, $\gamma = 1$ and $\theta \geq 1$, $\theta = 1, 3, 5, 7, 9$ are chosen. As shown in Fig. 7, it is concluded that the larger the θ value is, the shorter will be the network lifetime is.

As shown in Fig. 8, it is concluded that the larger θ is, the smaller energy consumption is.

It is reason that when θ is large enough, the effect of hops dominates in Eq. 3, RWGA is similar to minimal hop algorithm. RWGA emphasizes on minimum hops. Therefore, a link with long distance will be chosen. It increases the energy consumption and shortens the network lifetime. In addition, when $\theta<1$, there is no evident change in network lifetime or energy consumption

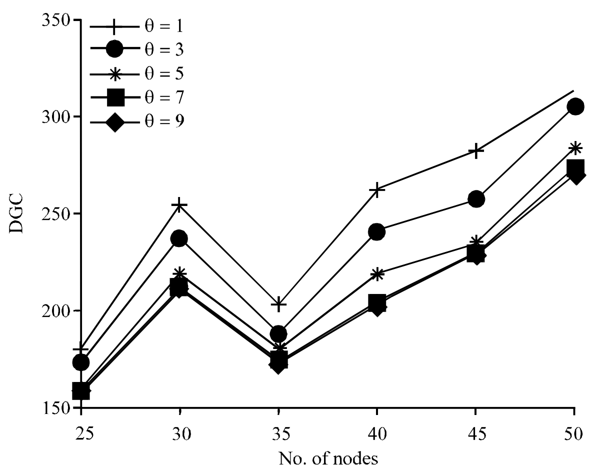

Fig. 7: Network lifetime (DGC) when $\theta \geq 1$

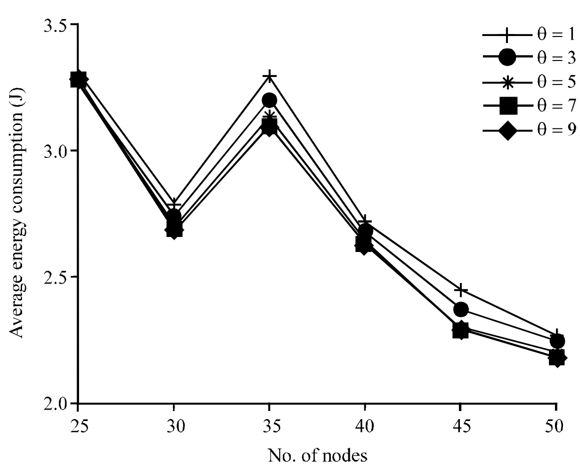

Fig. 8: Average energy consumption when $\theta \geq 1$

(the figures of simulation result are omitted here). In summary, choosing the appropriate θ ($\theta = 1$), RWGA has longer network lifetime.

SWGA ALGORITHM

Since, there are several parameters, the method of parameter increment is considered to get simulation results.

Firstly, the effect of λ on network lifetime and energy consumption is researched. When, the number of nodes is 30, λ is chosen 0, 0.01, 0.02,... 1 separately, δ is chosen 0, 0.01, 0.02,...(1-λ) separately, μ is chosen 0, 0.01, 0.02,..., (1-λ-δ) separately and ε is (1-λ-δ-μ). Iterative circle is used to get three-dimensional data of network lifetime and average energy consumption. By the analysis of the data, it is concluded that when $\mu = 0.1$, λ is close to 0 and δ is close to 0.9, the network lifetime will reach peak. As λ decreases, energy consumption will fluctuate and go down slowly (the figures of simulation result is omitted here).

In summary, choosing the appropriate λ (close to 0), SWGA has longer network lifetime.

Secondly, the remaining parameters δ, μ, ε are analyzed with the same method when λ is 0.01. As shown in Fig. 9, it is concluded that as the $\delta+\mu$ increases, network lifetime fluctuates and goes up slowly.

As shown in Fig. 10, it is concluded that as the $\delta+\mu$ increases, energy consumption fluctuates and goes down slowly.

In summary, choosing the appropriate value of $\delta+\mu$(close to 1), namely ε(close to 0), SWGA has longer network lifetime.

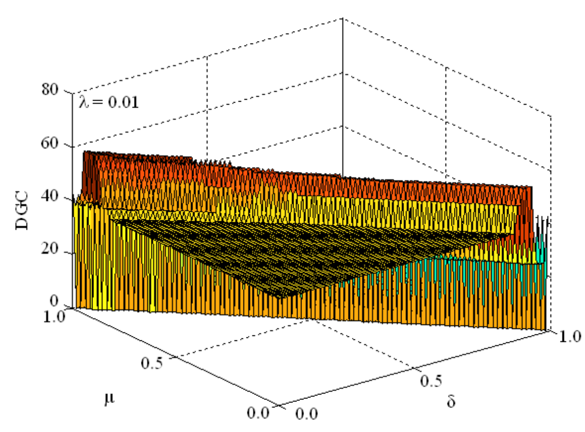

Fig. 9: Effect of δ and μ on network lifetime (DGC)

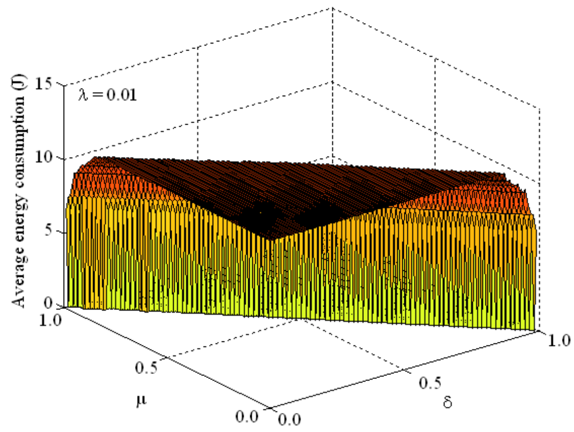

Fig. 10: Effect of δ and μ on average energy consumption

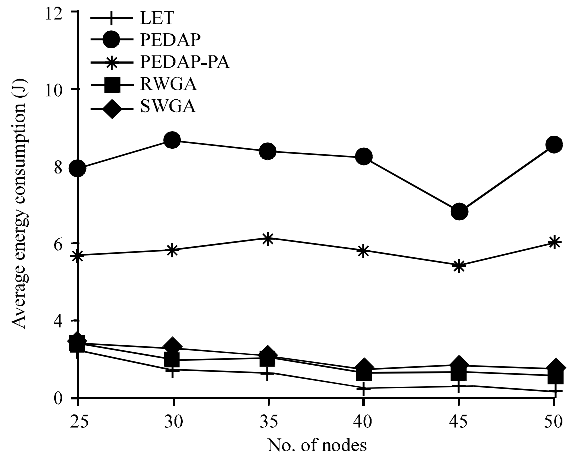

Fig. 12: Average energy consumption comparison

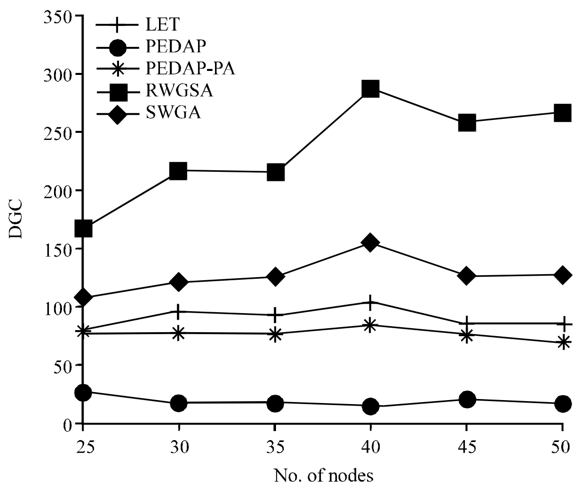

Fig. 11: Network lifetime comparison

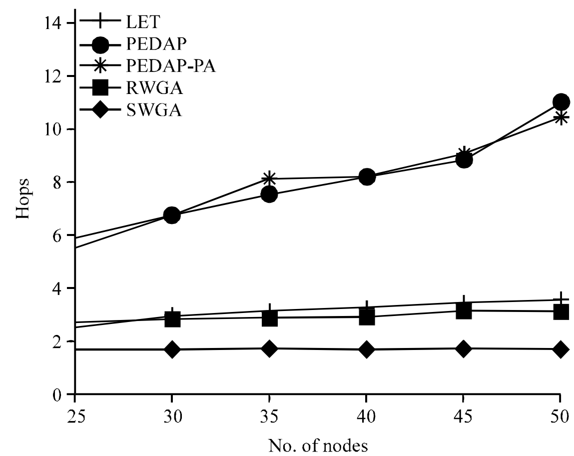

Fig. 13: Average network latency (hops) comparison

COMPARISON OF DATA-GATHERING ROUTING ALGORITHMS

According to the parameter research, $\alpha = 1$, $\beta = 1$, $\gamma = 0.7$, $\theta = 1$ and $\lambda = 0.01$, $\delta = 0.49$, $\mu = 0.49$, $\varepsilon = 0.01$ are chosen. The performances of algorithms are compared as follow:

As shown in Fig. 11, RWGA has the optimal network lifetime. SWGA has a little shorter. But they have far longer network lifetime than LET, PEDAP_PA and PEDAP. Therefore, RWGA and SWGA can prolong the network lifetime.

As shown in Fig. 12, RWGA, SWGA and LET have little difference. LET has lowest average energy the average energy consumption of the three algorithms is far lower than that of PEDAP and PEDAP-PA. Therefore, RWGA and SWGA remain energy consumption at a low level.

As shown in Fig. 13, SWGA has the lowest average network latency (hops). RWGA and LET have a little higher. But the average network latency of the three algorithms is far lower than that of PEDAP and PEDAP-PA. Therefore, RWGA and SWGA can reduce network latency.

CONCLUSION

RWGA and SWGA introduce two weight functions based on factors such as energy consumption, residual energy and hops. They use the shortest path tree with Dijkstra algorithm to gather node data. Simulation results show that by adjusting the parameters, it can prolong network lifetime, reduce network latency, balances node energy consumption and enable cost-effective energy consumption. Under certain conditions, RWGA and SWGA outperform PEDAP, PEDAP-PA and LET.

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REFERENCES

Chen, Y.R., L. Yu, Q.F. Dong and Z. Hong, 2010. Power control in wireless sensor network based on nearest neighbor algorithm. J. Zhejiang Univ. Eng. Sci., 44: 1321-1326.

Heinzelman, W.R., A. Chandrakasan and H. Balakrishnan, 2000. Energy-efficient communication protocol for wireless microsensor networks. Proceedings of the 33rd Hawaii International Conference on System Sciences, January 4-7, 2000, Washington, DC., USA. pp: 8020-8020.

Kalpakis, K., K. Dasgupta and P. Namjoshi, 2003. Efficient algorithms for maximum lifetime data gathering and aggregation in wireless sensor networks. Comput. Networks, 42: 697-716.

Lindsey, S. and C.S. Raghavendra, 2002. PEGASIS: Power-efficient gathering in sensor information systems. Proceedings of the IEEE Aerospace Conference, March 9-16, 2002, Los Angeles, CA., USA., pp: 3-1125-3-1130.

Tan, H.O. and I. Korpeoglu, 2003. Power efficient data gathering and aggregation in wireless sensor networks. ACM SIGMOD Rec., 32: 66-71.

Wang, H., N. Agoulmine, M. Ma and Y. Jin, 2010. Network lifetime optimization in wireless sensor networks. IEEE J. Selected Areas Communi., 28: 1127-1137.

Wang, J. and I. Howitt, 2005. Optimal traffic distribution in minimum energy wireless sensor networks. Proceedings of the IEEE Global Telecommunications Conference, Volume 6, December 2, 2005, St. Louis, MO., pp: 3274-3278.

Xu, N. and C.G. Cassandras, 2009. On maximum lifetime routing in wireless sensor networks. Proceedings of the 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference, December 16-18, 2009, Shanghai International Convention Center, pp: 3757-3762.

Zhu, Y.H., W.D. Wu and V.C.M. Leung, 2009. Energy-efficient tree-based message ferrying routing schemes for wireless sensor networks. Mobile Networks Appli., 16: 58-70.