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Energy-efficient Multipath Data Forwarding in Wireless Sensor Network

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Abstract: Network lifetime and energy consumption are two fundamental factors in wireless sensor network. Reducing nodes energy consumption in a time of transmitting packets will increase network lifetime. To avoid useless of wasting energy, selecting an energy-efficient routing protocol is very important. Splitting the original messages in several sub-packets, and join them by means of sink can reduce energy consumption substantially. In this paper we propose a routing protocol which improves its counterpart algorithm named Adaptive Energy and Location Aware Routing protocol (AELAR). This paper focuses on the energy efficiency in packets forwarding, improving multipath routing scheme in order to reduce energy consumption, which has several unique characteristics, such as delay tolerability. Simulation results show that proposed method achieves a high message delivery ration, low end-to-end delay and prolonging network lifetime. This new mechanism increases reliability and reduces energy consumption.

Key words: Wireless sensor networks, Energy-efficient routing, Multipath, Reliability

INTRODUCTION

Wireless sensor networks (WSNs) (Akyildiz, 2002) consist of large tiny power-limited nodes which are distributed over a certain area. A number of routing protocols which have been used on wireless sensor networks mainly focused on the power-limited nature of WSN. There are parameters in wireless sensor networks which relate to the great amount of energy consumption. These parameters can be listed as; high rate of packet loss, error in communication channel and packet congestion. Some of the conventional single path routing schemes may not be optimal to maximize the network lifetime and connectivity. Adaptive Energy and Location Aware Routing protocol in Wireless Sensor Network called AELAR, which is location-based, energy-aware, and scalable. It first presents a novel method of dividing routing request zone and then constructs a select equation for a node to choose its next hop. Both the routing request zone and the select equation can be adjusted by the node according to its own location. This adaptive mechanism ensures that the selection paths by AELAR are as short as possible (Hong Fu,). In our present scheme the original messages split in several sub-packets and forward each of them using the AELAR protocol. The splitting procedure is realized applying the Chinese Remainder Theorem (CRT) algorithm (Giuseppe Campobello; Campobello, 2008), which is characterized by a simple modular division between integers. The sink node, once all sub-packets (called CRT components) are received correctly, will recombine them, thus reconstructing the original message. The simple splitting procedure is particularly helpful for those forwarding nodes that are more solicited than others, due to their position inside the network. Our mechanism increases reliability, reduces delay and prolonging the network lifetime. End-to-End delay is low due to the multipath routing among sensors and forwarding parallel mood. This method shares characteristics of other sensor networks, such as delay tolerability, limited battery power and a short radio transmission range. The rest of the paper is organized as follows: Section II presents related work. We describe the Chinese Remainder Theorem (CRT) in section III. Section IV describes AELAR, section V presents proposed work, section VI details our simulation results and finally section VII concludes the paper.

Related Work:

The Delay/Fault-Tolerant Mobile Sensor Network (DFT/MSN) is a paradigm for pervasive information gathering. DFT/MSN consists of two data delivery schemes, namely the Replication-Based Efficient Data Delivery schema (RED) and the Message Fault Tolerance-Based Adaptive Data Delivery schema (FAD). Both schemes aim to minimize the overhead and maximize data delivery in wireless sensor networks. In the RED,

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retransmission function is done by the source node and in the FAD is done according to its fault tolerance by the source and the intermediate nodes. In RED, data transmission is based on the delivery probability. If p_i be the delivery probability of sensor *i*, that p_i is initialized with zero and updated with timer. A data message transmits during Δ and then reduces its delivery probability, Thus during the data transmission, when the source node i, knows their delivery probability, then the source node transmits its message to the other nodes such as j, which has the highest delivery probability ($p_j > p_i$). The FAD schema unlike the RAP, transmit data message to the other nodes but it keep a copy of the data after its transmission (Yu, 2007). Original greedy forwarding is one of the most routing models in wireless sensor networks, which transmits data message with selecting a neighbor node that it is closest to the sink. Then the selection node selects the next one by location information. This method is very simple. In wireless sensor networks where the quality of link is very impermanent, so quality decrease when distant is far. This model selects a farthest neighbor node for forwarding to the sink, thus original greedy forwarding makes several retransmissions (Karp, 2000; Ferrara, 2005). Another study proposes a packet delivery mechanism for energy aware called Multi Path and Multi-Speed Routing Protocol (MMSPEED), those overlays on the network layer and medium access control layer. This protocol addresses reliability dependency and presentation multiple levels of delivery speed. In MMSPEED each node is aware of its neighbor nodes geography information within its radio range. Each node transmit data message to the closer neighbor node, so the data can be delivered to the sink without learn about global information. Thus MMSPEED provides multiple delivery speed, but doesn't keep an individual node's energy and doesn't remove node's energy saves when selection paths for forwarding to the sink, so many data packets are routed over the same routes. It's opposite of load balancing in wireless sensor network (Emad Felemban, 2006). Energy-Efficient Multiple Paths Routing Algorithm (EMRA) for WSNs is a routing algorithm that increases resilience to node failure. This algorithm is based on data-centric and location-based to find discrete paths. This application is used to control overhead and energy consumption in the network. In EMRA the source node floods data message to the sink, when after the sink node received the data message can find main path. To find other secondary paths the sink node tries its neighbor nodes by intermediate nodes, so reduce the delay to set up multiple paths (Kang, 2008). In (Ghaffari, 2011), the authors propose a new QoS-based routing protocol for wireless sensor networks that considers the reliability, timeliness and residual energy of single hop neighbor nodes for selecting optimum next forwarding node.

Chinese Remainder Theorem:

In this section we will briefly review the Chinese Remainder Theorem; in the simplest case, this theorem can be described as follows (Giuseppe Campobello,):

Given N primes p_i< 1, which iє {1... N}, M will be primes product, i.e. $M=\Pi_i p_i$. By assuming m as original packet, then set of integers $\{m_1, m_2 \ldots m_N\}$ will be sub-packets, considering the condition m >M, m can be obtained from the equation (1). Notice that in equation (2), q_i is c_i modular inverse.

$$m = (\textstyle\sum_{i=1}^{N} c_i * m_i) mod\ M \quad (1)$$

$$c_i = Q_i * q_i \quad (2)$$

$$Q_i = \frac{M}{p_i} \quad (3)$$

$$m_i = m\ mod\ p_i \quad (4)$$

For example, consider a system that is m = 64 and we want sent message by the Chinese Remainder Theorem, instead of forwarding complete packet (m), knowing the set of primes p_i={3,5,7} that iє{1,2,3} can split it into three sub-packet by the equation(3) and the sub-packets sent by the intermediate nodes to the sink.

Considering the above relations can be proved that 7 bits are required to show this message, which cannot be considered as more than three bits for each sub-packet. For example in figure(1), if B,C and D received message m from node A, each of them will execute the above method and calculated sub-packets by m_i equation with i∈[1,2,3] and transmit sub-packets to S node instead of m (Giuseppe Campobello, 2008).

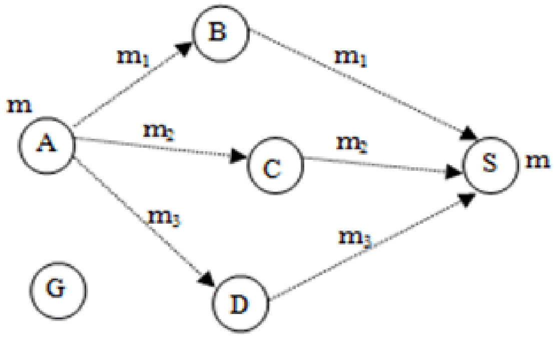


Fig. 1: Example of forwarding the main packet after division.

In general, splitting packet to several sub-packets with low number of bits will reduce energy consumption. Mainly selecting appropriate primes has a major role in energy storage. The maximum number of sub-packets bits and theoretical maximum energy reduction factor (MERF) can be achieved by following equations:

Where w_{CRTmax} and w are respectively the maximum number of CRT components and number of bits in original packet. For instance in the previous example is w = 7 and w_{CRTmax} =3 and MERF= $\frac{7-3}{7} \cong 0.57$ this means that about 57% of the energy could be saved by considering the proposed forwarding scheme (Giuseppe Campobello,).

Adaptive Energy and Location Aware Routing:

This section will review the AELAR algorithm. AELAR is location-based, energy-aware, and scalable to discover the paths between the source node and the sink. It first presents a novel method of dividing routing request zone and then constructs a select equation for a node to choose its next hop. To select an appropriate node as the next hop for forwarding data packets, AELAR strikes a balance between residual energy and distance metrics. AELAR use the natural logarithm function for residual energy level to enlarge the residual energy difference among neighboring nodes. Letting e_x be the residual energy of a neighboring node *j* and e_i be the initial energy of node *i*, d_{id} and d_{jd} are respectively the distance from node *i* and node *j* to the sink. Then, the node *j*'s select factor f_j is defined as (7) (Hong Fu,):

$$f_j = \ln\left\{\left(\frac{e_r}{e_i}\right)^{\alpha}\left(\frac{d_{id}}{d_{jd}}\right)^{\beta}\right\} \tag{7}$$

Where α and β are the weight factors of energy consumption ratio and distance ratio.

AELAR selects the neighboring node that not only locates in the routing request zone but also has the greatest value of f_j as the next hop. The energy effect on the above equation will drastically increase if the residual energy of the node is too low. So, nodes with too low residual energy will be difficult to be chosen as the next hop in the route discovery, which is helpful to balance the energy expenditure (Hong Fu,). In this paper we use AELAR in our routing algorithm for three paths to reduce energy consumption.

Proposed Scheme:

If all message's bits forward through one route which is selected as a appropriate route, the energy of theses nodes will be out of use as time passes, splitting the message into several sub-packets and forward them through several neighboring nodes will decrease the energy usage of each nodes and therefore increase the lifetime of network because The network load will distributed on multiple paths instead of focus on only one path. In this way, more nodes take part in transmitting data packets, and node energy cost will more balanced or the entire wireless network. In order to evaluate network lifetime, the following equation is used:

$$NLT=\frac{\sum_{i=1}^{n}(e_{i,res}-e_{i,n})}{e_{int}} \quad (8)$$

Where $e_{i,res}$ illustrates the residual energy level of node i and $e_{i,n}$ indicates needed energy for packet forwarding of node i, also e_{int} represents initial level of energy.

On the other hand because sub-packets are forwarded parallel, destination will receive the whole packet sooner, so end-to-End delay will decrease too. The effect of proposed scheme on network lifetime is shown in figure 3.AELAR selects one neighboring node that is in respective area. In proposed scheme original message splits into three sub-packets based on CRT algorithm, and then three neighboring nodes will select instead of one neighbor node to forward three sub-packets. Original message will split based on CRT algorithm and each sub-packet will forward through each selected neighbor nodes. Figure 2(a) shows an example of candidate neighboring nodes of the route to the destination which are located in the overlap area of an elliptic region and transmission radius of source node *i*. Thus, reduces delay and energy consumption. Figure 2(b) shows coordinate finding of *i*th next neighbor node, which is close to the sink. The neighbor coordinates can be obtained as follows:

$$\begin{cases} x_2 = r * \cos\theta + xi \\ y_2 = r * \sin\theta + yi \end{cases} \quad (9)$$

$$\theta = \pi - \mathrm{Arccos}\left(\frac{xi}{\sqrt{xi^2+yi^2}}\right) \quad (10)$$

Where, r is node communication radius, x_2 and y_2 the virtual coordinate of a neighboring node, x_i and y_i coordinate of given node *i* (Source node), and θ is the angle between the x-axis and the sink.To evaluate the two parameters of elliptic (a, b), we assume that the value of a, equal to transmission radius r and b, can be obtained as follows (Hong Fu,).

$$b = \sqrt{2rd_{id} - r^2} \quad (11)$$

$$d_{id} = \sqrt{x_i{}^2 + y_i{}^2} \quad (12)$$

Where, d_{id} is the distance from node I to the sink.

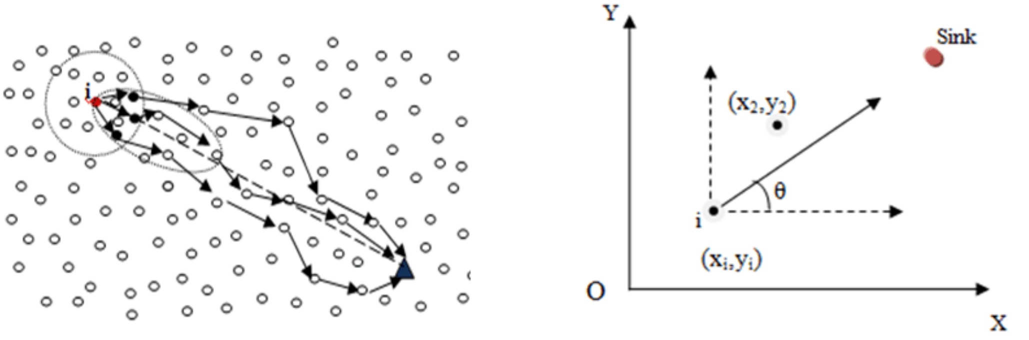
The routing request zone is represented by Equation (13). To identify the routing request zone following equations is used; this formula assigns the overlap area of elliptic region and radio transmission of source node (Hong Fu,).

$$\frac{(x'-a^2)}{a^2}+\frac{(y)^2}{h^2}\leq 1 \qquad \text{and} \qquad d_{ij}\leq r \quad (13)$$

Where, d_{ij} is the distance from node *i* to neighboring node *j* and (x`, y`) are the coordination of closer neighboring nodes to the sink.
This function is acting for the three neighbor node of source node *i*
To evaluate the node energy consumption we use following equations:

$$E_T=\frac{\sum_{i=1}^{M}(e_{i,int}-e_{i,res})}{M*dataN} \quad (14)$$

Where, M is the number of nodes, $e_{i,int}$ and $e_{i,res}$ are respectively the initial and residual energy levels of node *i*, and *dataN* is the number of data packets received by sink. By splitting original message into



(a) Selection the three shortest paths (b) coordinate finding of i'th neighboring node

Fig. 2: Routing algorithm with three paths for source node I.

sub-packets and using multipath for transmission, although the number of nodes that are involved in forwarding operation increased but nodes use less energy, because they are responsible of forwarding a part of message instead of whole message so energy consumption of nodes will decrease.

Performance Evaluation:

We have performed extensive simulations to evaluate the performance of the proposed scheme. In this study the proposed protocol is compared with Adaptive Energy and Location Aware Routing (AELAR). The simulation parameters are described as follows: 500 sensors are randomly deployed in 100*100 m^2 sensor fields and there is one sink in the top left corner. We assume that the distributed of nodes are in a way that each node has at least three neighbor node toward the sink. All sensors are homogeneous and have the same ability of communication range *r*. table 1 shows the simulation parameters.

Table 1: Simulation parameters

Parameter	Value
Number of nodes	500
Simulation area	100m*100m
Sensor distribution	Uniform random
Location of Sink	top left corner
Radio range	10m
MAC layer	IEEE 802.11
Bandwidth	200KB/S
Initial battery charge	20 Joule

The effect of proposed scheme on End-to-End delay is shown in figure 3. According to multipath forwarding of fragmented message, the destination will receive packet sooner than forwarding message bits consecutive and from single route so the delay will impressively decrease. Figure 4 shows the comparing of average distance of the forwarded path. The analyzed results shows that the average distance in Triple-path is lower than single path, that is because of forwarding from different paths with different distance.

Figure 5 demonstrate energy consumption of WSN. In triple-path protocol three sub-packets distributed on multiple paths instead of concentrating on only one path thus energy cost of nodes will be balanced for the entire wireless sensor network therefore energy consumption of each packet will reduce because each node forward a few number of original message.

The other factor that is so important in WSN is network lifetime and can be calculated by equation (8). Figure 6 illustrated the impact of proposed scheme on network lifetime. Since each node consumes less energy while forwarding, therefore the power factor will improved and the network lifetime will increase effectively.

Conclusion:

One of the critical issues in WSN applications is energy-efficient routing. Due to energy and resource constraints of the wireless sensor node in WSNs, contouring protocols with lower energy cost and longer network lifetime are desirable. In this paper, we proposed a new multipath routing protocol for wireless sensor

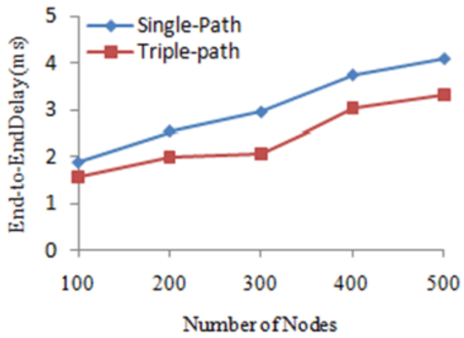


Fig. 3: Average End-to-end Delay.

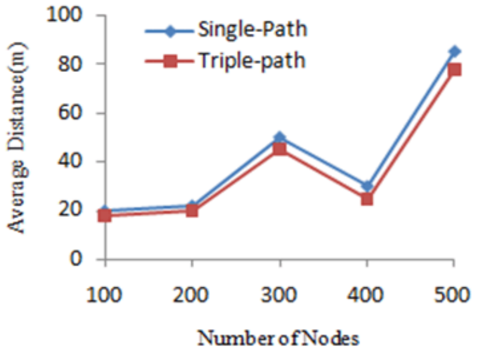


Fig. 4: Average Distance.

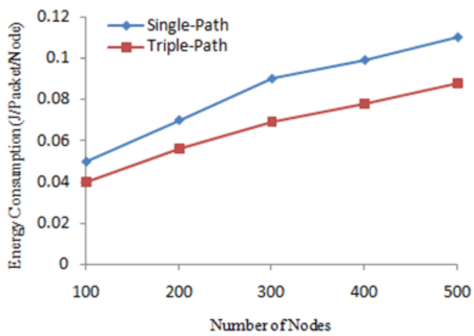


Fig. 5: Total Energy Consumption.

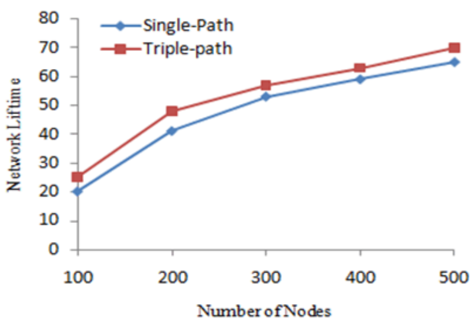


Fig. 6: Network Lifetime.

networks. The proposed scheme splits the message in three sub-packets and forwards them through multipath across the sink, which balance network load. The simulation results show the effectiveness of proposed protocol to reduce delay and energy consumption and therefore increases network lifetime. Our further work is to improve the algorithm to increase network reliability.

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