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A Transmission Method to Guarantee QoS Parameters in Wireless Sensor Networks

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Abstract: Energy-efficient and reliable data transmission are crucial issues in WSNs due to the energy constraints and high packet loss rates, In order to increase network reliability and throughput, multipath forwarding is used in many applications. However because of using multiple paths between source and destination, the multipath forwarding mechanism increases network overhead. By splitting the original messages and forwarding each sub-packet through multipath routing protocols, energy consumption and network overhead can be reduced. This paper proposes a flexible recovery mechanism which increases reliability and minimizes both energy consumption and delay. The proposed scheme caches sub-packets at some special intermediate nodes and retransmits from these nodes instead of source node whenever it is necessary. Performance evaluations of sub-packet caching (SPC) demonstrate that using multipath forwarding with caching data can effectively increase reliability and reduce energy consumption and latency.

Keywords Wireless Sensor Networks, Energy-efficient Routing, Multipath, Reliable Transmission, loss Recovery

1. Introduction

With the development of miniaturized sensor nodes, wireless sensor networks (WSNs) [1] have become a promising technology that can play an essential role in many vital and critical fields. Sensors are responsible of forwarding significant data, immediately and efficiently to the base station for processing. Increasing reliability in WSNs is a challenging task which have made it the target of many studies. Because sensor nodes are powered by life-limited and irreplaceable batteries, minimizing the power usage of each node is important and must be considered while designing WSNs. In order to increase reliability, multipath forwarding is used in many applications. Single path forwarding enhances the choice of the same path that can cause dropping of the most used nodes. Inverse multipath routing allows forwarding packets through multiple paths between source and destination as a result of which multiple copies of data will be sent. Although it can remarkably enhance network overhead and consume more energy, reliability will be guaranteed. To overcome these inherent properties of many multipath routing protocols, the splitting approach can be used. Original messages can split in several sub-packets to be forwarded by multipath routing algorithm such that each node will forward only small sub-packets. The splitting procedure that is used in this paper is the Chinese Remainder Theorem (CRT) [4], which is characterized by a simple modular division between integers [9]. Meanwhile corrupted and lost packets are unavoidable facts in WSNs because of data transmissions over radio links. A packet loss can fall out due to wireless link errors or destroyed nodes due to environmental events or node crash down due to energy depletion and decreased network efficiency. This paper proposes a flexible recovery mechanism for lost packets which guarantee energy-efficient reliable data transmission. The proposed scheme caches sub-packets at some special intermediate nodes and retransmits from these nodes whenever it is necessary. Hop by hop protocol is an approach that caches data to every intermediate node. NBH [2] not only increases reliability, but it also increases network overhead. Inverse, End-to-End [3] protocol does not perform data caching. Therefore the network overhead will be balanced while the reliability decreases. Providing some reliability support at intermediate nodes is more energy-efficient. The proposed method which is called SPC fulfills this requirement by caching packets at some special intermediate nodes.

The remainder of this paper is organized as follows: Section II presents related work, subsequently section III presents the Chinese Remainder Theorem (CRT). We describe the proposed scheme in section IV. Section V details our simulation efforts and finally section VI concludes the paper.

2. Related Work

Reliable transmission is an important issue in extremely unreliable link environments of wireless sensor networks, which have become more difficult to attain due to the increased number of nodes. Recent studies have shown that in WSNs links are highly unreliable due to many factors such as interference, attenuation and fading [5-6]. Messages in the network are delivered according to their deadlines. Several routing protocols have been proposed to provide reliable data transmission. In [7] a Distributed and Reliable Data Transmission (DRDT) scheme with the objective of efficiently guaranteeing reliable data transmission is provided which increases reliability by cooperative retransmission task by helping nodes.

DRDT effectively reduces the number of retransmissions by using helping nodes. Selection of the helping node is based on the quality of the link to the receiver node. DRDT guarantees high energy-efficiency and effectively reduces

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end-to-end transmission delays. Ganesan *et al*. reported that packet loss can occur over a short distance while the distribution of packet reception over an area is not uniform and low-power environments have quite asymmetric links [8]. The authors of [9] proposed a multi-path routing model for WSNs referred to as Multi-Constrained Multi-Path routing (MCMP) where packet delivery from nodes to the sink is achieved based on QoS constraints expressed in terms of reliability and delay. This model addresses the issue of multi-constrained QoS in wireless sensor networks taking into account the unpredictability of network topology and trying to minimize energy consumption. Couto *et al*. [10] have measurements for DSDV and show that with minimizing the hop count, the distance traveled maximizes by each hop and it increases the loss ratio. Another study proposes a packet delivery mechanism for energy aware called Multi Path and Multi-Speed Routing Protocol (MMSPEED), that overlays on the network layer and medium access control layer. This protocol addresses reliability dependency and presents multiple levels of delivery speed. In MMSPEED each node is aware of its neighbor nodes' geographical 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 learning global information. Thus, MMSPEED provides multiple delivery speed, but it does keep an individual node's energy and it does not remove node's energy except for when it selects paths for forwarding to the sink. Therefore, many data packets are routed over the same routes. It is the opposite of load balancing in wireless sensor networks [11]. In [12] a Cluster-Based Forwarding (CBF) is proposed which guarantees reliability by using a cluster that consists of helper nodes with good link quality. The disadvantage of CBF arise when the location of the sink changes, so all the nodes should select helping nodes again. Therefore, CBF cannot fully guarantee the reliability of realistic wireless sensor networks. The Energy-Efficient Multiple Paths Routing Algorithm (EMRA) for WSNs is a routing algorithm that increases resilience to node failure. This algorithm is based on a data-centric and location-based approach 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 receives the data message it can find the main path. To find other secondary paths, the sink node tries its neighbor nodes by intermediate nodes. Thus, it reduces the delay to set up multiple paths [13]. Using caching in WSNs was first proposed in [14]. The authors of [15] proposed a multi-path-based distributed TCP caching algorithm, which uses redundant paths and hop-by-hop local retransmission to ensure reliable transport, on the basis of the original single-path-based algorithm. A new structure of caching is proposed in [16] which is called Active caching (AC). AC provides a tradeoff between end-to-end delays and memory requirements and more reliability.

3. The Chinese Reminder Theorem

In this section we will briefly review the Chinese Remainder Theorem. In the simplest case, this theorem can be described as follows [17]:

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

$$m = (\sum_{i=1}^{N} c_i * m_i) \ mod \ M \quad (1)$$
$$c_i = Q_i * q_i \quad (2)$$
$$Q_i = \frac{M}{p_i} \quad (3)$$
$$m_i = m mod p_i \quad (4)$$

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 $i\epsilon\{1, 2, 3\}$can split it into three sub-packet by equation (3) and the sub-packets sent by the intermediate nodes to the sink.

Considering the above relations it 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 Fig.1, if B, C and D are the received message m from node A, each of them will execute the above method and calculated sub-packets by m_i equation with $i\epsilon\{1, 2, 3\}$ and transmit sub-packets to S node instead of m.

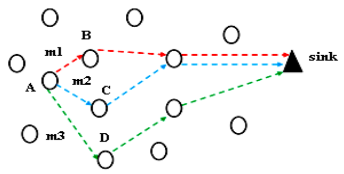


Fig. 1. Example of forwarding the main packet after division

$W_{CRT_{max}}$ Indicates the maximum number of CRT components where w is the number of bits in the original packet.

$$W_{CRT_{max}} = max(\lceil log \ (p_i) \ \rceil \quad (5)$$

In general, splitting packet to several sub-packets with a low number of bits will reduce energy consumption.

The maximum number of sub-packets bits and theoretical maximum energy reduction factor (*MERF*) can be obtained from the following equations:

$$MERF = \frac{(w-W_{CRT_{max}})}{w} \quad (6)$$

Selecting appropriate primes has the most important role in energy storage.

4. The Proposed Approach

Reducing delay, improving energy consumption and maximizing reliable data transmission are commonly discussed issues in WSNs. In many applications, multipath forwarding is used in order to increase both reliability and throughput. Hence, the delay and packet loss ratio will be extremely reduced because of using multiple paths in packet transmission. However, traffic congestion and network overhead increase because of sending several copies of a packet. By splitting the original messages into several sub-packets, each node will be responsible of forwarding a small sub-packet; consequently low power consumption of each node and network balancing will be achieved. The greedy forwarding selects a nearest neighbor node from the source node to the sink as the next forwarding node Storage data packets at some intermediate nodes between the source and the destination for retransmitting the missing data packet can be an appropriate solution to reduce delay and increase reliability.

The queuing model of the sensor nodes of the proposed scheme is shown in Fig.2. The forwarding mechanism that is used to delivered packets to the destination is described in [18], which is the author's previous paper.

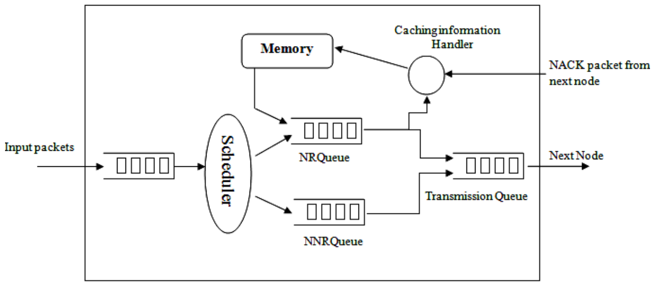


Fig 2. Queuing model of sensor nodes

In order to achieve a high delivery ratio, minimize network overhead and ensure high reliability, caching sub-packets along the multipath forwarding can be used. In the proposed scheme, the splitting procedure that is used to break up the original message is the Chinese Remainder Theorem (CRT). Two parameters play an essential role to detect whether caching is necessary or not. This method considers the reliability of the link rate as a threshold. Probability of Error can be calculated as follows [19]:]

$$POE = \frac{1}{2} * (1 - erf)\sqrt{\frac{E_b}{N_0}} \tag{7}$$

where *erf* is the error function, E_b is a bit of energy derived and N_o is the noise power spectral density.

Each node has the ability to count the number of NACK packets that receive from further nodes [20]. Probability of Caching (POC) is obtained by POE and NON [t-1] which refers to Number of NACK packets that node *n* receives in t-1.

Depending on the type of data that sensors should report to the sink, the Scheduler classifies received packets as need reliability (NR) packet or non-need reliability (NNR) packet and sends them to NRQueue or NNRQueue queues, respectively. By using the algorithm described in Fig.3, the caching information handler can decide whether caching is needed or not. Packet will send the memory of current node to cache for a special period of time if caching condition becomes true.

In WSNs, information that has been collected by the sensors must be delivered in a special time. Otherwise, data will be useless. Successfully forwarding in a packet timeline can be achieved in a balanced network. The proposed method minimizes packet overhead and ensures high throughput by multipath forwarding of sub-packets.

The following equation can be used to calculate the network load balancing when sub-packets are distributed to be forwarded through different multipath [21]:

$$\varphi(\bar{r}) = \frac{(\sum_{j=1}^{N} r_j p_j)^2}{N\sum_{j=1}^{N}(r_j p_j)^2} \tag{8}$$

where φ illustrates load balance ratio, the vector $\bar{r}$ denotes the traffic rates allocated to all available routes, r_j and p_j are respectively the traffic flow and the product of the path cost allocated to path j.

In the proposed scheme, the main packet will split into several sub-packets only in the source node. Equation (9) presents the transmission cost of each node. It reflects both communication overhead and energy-efficiency [7]:

$$TransmissionCost = \frac{T}{U.N} \tag{9}$$

where N represents the average number of hops in the paths, T shows the total bits each node transmits, and U denotes the number of useful bits that the sink received.

By using (8) the reduction of network overhead is obvious.

This paper is going to reduce energy consumption while minimizing the delay. To evaluate the node energy consumption we use following equation:

$$E_T = \frac{\sum_{i=1}^{M}(e_{i,int} - e_{i,res})}{M*N} \tag{10}$$

where M is the number of nodes, $e_{i,\ init}$ and $e_{i,\ res}$ are the initial and residual energy levels of node i, respectively and N is the number of data packets received by the sink.

Energy is a major factor which impacts the network life time. By reducing energy consumption and delay, the network lifetime will be prolonged. The following equation is used in order to obtain network lifetime:

$$NLT = \frac{\sum_{i=1}^{n}(e_{i,res} - e_{i,n})}{e_{int}} \tag{11}$$

where $e_{i,n}$ indicates the energy needed for packet forwarding of node i, and e_{int} represents the initial level of energy.

```
n=1      // current node in the path to destination
Loop n< N
(POE) n ←½ * (1-erf) √Eb/N0
(POC) n←(POE) n + NON [t-1] n
If (POC) n < θ1 and NON [t-1] n< θ2
Forward the packet normally and without caching
n←n+1
Return
Else if (POC) n > θ1 or NON [t-1] n> θ2
First cache the sub-packet and then forward to      next hop
n←n+1
Return
End loop
```

Fig 3. Caching algorithm at *n*-th node

5. Performance Evaluation

In this paper, a homogenous WSN has been considered. For the simulation, we assume 100 sensors that are randomly distributed through the sensing area of 100*100 m^2. Table 1 lists the main parameters of simulation.

We consider three different parameters to evaluate the performance of the proposed method: End-to-End packet delay, energy consumption and successfully delivered packets ratio.

The simulation has been done in two parts; splitting the main packet, respectively into two and three sub-packets. Fig. 4 and Fig. 5 show the performance comparison of AELAR, GEAR, and SPC. Due to the forwarding multipath (equal to the number of sub-packets) with different distances, the average distance will be lower than forwarding from a single path and also whenever the sub-packet is lost, the delay in SPC will be reduced and be lower than the other two protocols because of caching sub-packets in some intermediate nodes and retransmission from those nodes instead of source node as shown in Fig.4 (a) and Fig. 5 (a).

Table 1. Simulation Parameters

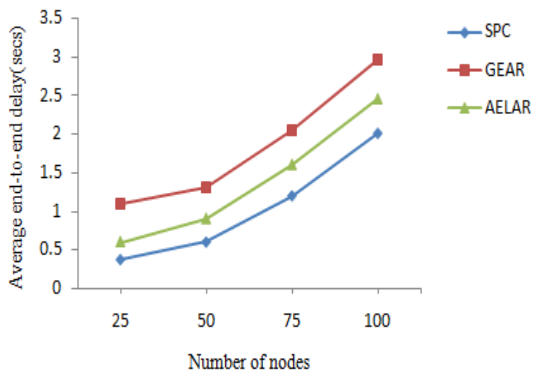
Parameter	Value
Number of nodes	100
Simulation area	100*100
Number of sink	1
Sensor distribution	Uniform random
Location of Sink	top left corner
Radio range	5m
MAC layer	IEEE 802.11
Bandwidth	200KB/S
Initial battery charge	3.3 Joule

To calculate the number of packets that reach the destination, the Data Delivery Ratio can be used [22] and it is express as:

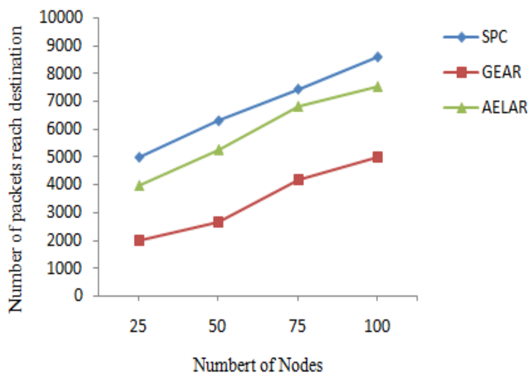
$$\text{Data Delivery Ratio} = \frac{\text{Succesfully delivered data}}{\text{Required Data}} \qquad (12)$$

This equation demonstrates both the number of data packets that are sent by the source and the number of data packets received by the sink. In the ideal condition the result should be equal to 1.

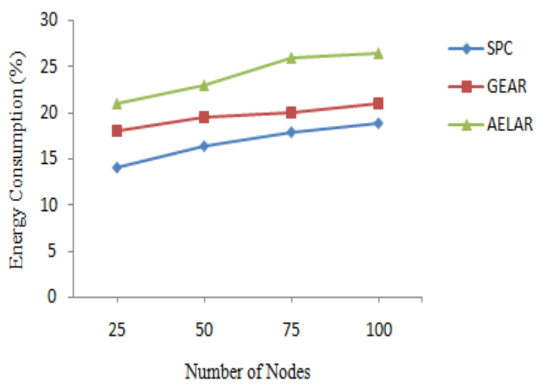
Due to caching in SPC scheme the percentage of packets which can successfully be delivered to the destination will increase. This fact is shown in Fig.4 (b) and Fig.5 (b). By getting closer to the ideal condition, high reliable forwarding will be obtained. By splitting the original message into sub-packets and using multipath for transmission, nodes use less energy while forwarding although the number of nodes that are involved in forwarding operation increased. This is because they are responsible for forwarding only a part of the message instead of the whole message, so energy consumption of the nodes will decrease. By using a CRT-based Packet Splitting Algorithm and splitting the original message into two and three sub-packets, respectively about 71% and 57% of the energy could be saved. The simulation results in Fig.4 (c) and Fig.5 (c) indicate this theme.



(a) Average end-to-end delay

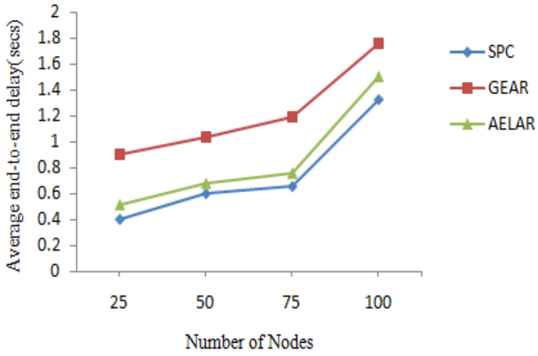


(b) Number of packet that reach destination

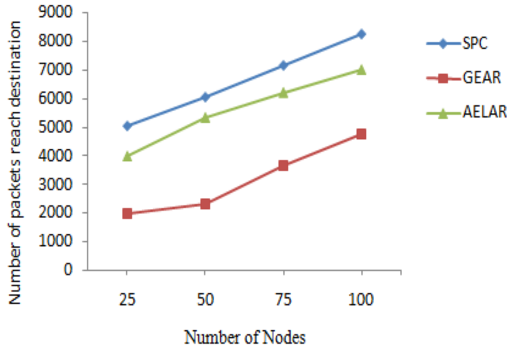


(c) Energy consumption

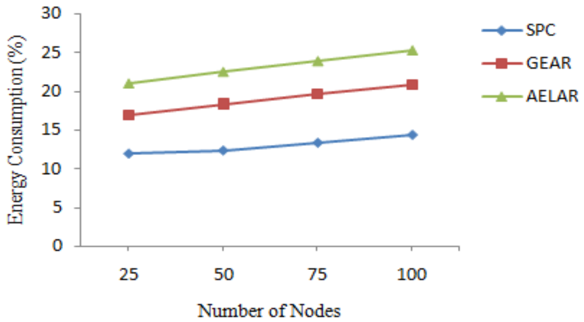
Fig 4. Simulation results for evaluating the performance of Splitting-packet cashing with 2 sub-packets (a, b, c)



(a) Average end-to-end delay



(b) Number of packet that reach destination



(c) Energy consumption

Fig 5. Simulation results for evaluating the performance of Splitting-packet cashing with 3 sub-packets (a, b, c)

6. Conclusion

This paper describes the splitting of original packets into several sub-packets based on the CRT algorithm, and uses the multipath to forward these sub-packets to the destination. A new Caching approach is proposed which considers two parameters; link error that is calculated as the probability of error and numbers of NACK packets that the current node has received from the next node in past times. The proposed scheme that is called SPC optimizes the tradeoff between the reliability and energy-efficiency, minimizes the network overhead, increases packet reception ratio and prolongs network lifetime.

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