A Novel Real-Time Power Aware Routing Protocol in Wireless Sensor Networks

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Summary

One of the most important and challenging issues in real-time applications of resource-constrained wireless sensor networks (WSNs) is providing end-to-end delay requirement. To address such an issue a few QoS routing protocols have been proposed. THVR (Two-Hop Velocity based routing protocol) is newly proposed real-time protocol while it is based on the concept of using two-hop neighbor information for routing decision. In this paper we propose a novel real-time Power-Aware Two-Hop (PATH) based routing protocol. PATH improves real-time performance by means of reducing the packet dropping in routing decisions. PATH is based on the concept of using two-hop neighbor information and power-control mechanism. The former is used for routing decisions and the latter is deployed to improve link quality as well as reducing the delay. PATH dynamically adjusts transmitting power in order to reduce the probability of packet dropping. Also PATH addresses practical issue like network holes, scalability and loss links in WSN's .We simulate PATH and compare it with THVR. Our simulation results show that PATH can perform better than THVR in term of energy consumption and delay.

Key words:

Delay, QoS, routing, Forwarding velocity, WSN

1. Introduction

Wireless sensor networks (WSN) represent a new generation of embedded systems for routing sensory data from the originator sensor node to the control station [1]. Recent technological advances have enabled the development of tiny battery-operated sensors [2]. Although energy efficiency is usually the primary concern in WSNs, the requirement of low latency communication is getting more and more important in new applications. Examples of real-time (RT) sensor applications can be found in many military or environmental surveillance systems [3]. In target tracking applications of WSNs the collected data must reach the control unit in a limited duration to ensure an effective RT tracking of the observed region [4]. In medical applications [5], sensor devices are required to capture RT vital signs from patients, critical sensory data must be displayed at the doctor's control monitor in time so as to take prompt actions.

Current research on routing in wireless sensor networks mostly focused on protocols, which are energy-aware to maximize the life time of the sensor network [6]. Recently a few routing protocol for providing quality of service in wireless sensor networks are proposed. In this way SPEED [7] is a real-time routing protocol for soft end-to-end deadline.

This protocol guarantees deadline by maintaining a packet delivery speed across the network which should be greater than or equal to the desired velocity *v.* the required velocity defined by the ratio of straight line distance from source *s* to target *t* over the required deadline. In SPEED if there is no neighboring node which can support the desired velocity, the protocol probabilistically drops packets to regulate the workload. RPAR [8] is a real-time power-aware routing (RPAR) protocol that is proposed to achieve application specified communication delay at low energy cost by dynamically adjusting transmission power and routing decisions. Both RPAR and SPEED operate based on the one-hop neighborhood information. THVR [9] is newly proposed real-time protocol. It has also adopted the approach of mapping packet deadline to a velocity like SPEED, which is known as a good metric to delay constrained packet delivery. However, its routing decisions will be made based on two-hop neighborhood information. It has achieved lower end-to-end deadline miss ratio and higher energy utilization efficiency because using more neighbor information for routing result in better performance.

Both THVR and SPEED have one important drawback. If the forwarding unit cannot find any node that can provide require velocity, the packet will be dropped. It forces some delay and energy consumption overhead to network and can cause problem when the packet is mission critical. In order to addressing this problem we adopt the concept that has been used in RPAR and integrate it with THVR. We propose a novel Power-Aware Two-Hop, PATH, real-time routing protocol that integrates power control concept with THVR for decreasing the probability of packet dropping.

The rest of paper is organized as follows. In section 2 important issues which should be considered in PATH design will be denoted. Section 3 introduces the design goal and motivation of PATH. The description of PATH protocol is presented in section 4. In section 5 PATH will

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be compared with THVR protocol and simulation result will be presented. Finally the paper is concluded in section 6.

2. Important issues in the design of PATH

In this section we discuss two important concepts that are used in the design of PATH. First we identify the effect of the using two-hop neighbor information on real-time performance and then we investigate the advantages and disadvantages of using power control on delay and network capacity.

2.1 Impact of using Two-hop neighbor information on real-time performance

Using local information for routing packets is preferred in WSNs because there is no need for storing routing tables and also localized routing protocols scale well when the size of network increases. However it is obvious that using more information can result in better choice for routing decisions. In [14] it is shown that using Two-hop neighbor information can lead to lower number of hop than using only one-hop neighbor information. THVR uses this concept in routing real-time data and obtain better result in term of energy consumption and packet delay [9]. In this paper we adopt this idea and integrate it with power control mechanism for further improving real-time and energy performance.

2.2 The advantages and disadvantage of increasing transmission power

There is an inherent tradeoff between transmission power and communication delay [8]. Increasing transmission power effectively improves link quality [11] thus it increases the delivery velocity. The concept of using power control in the routing of the delay sensitive packets is also introduced in [8]. Such an idea is not a new concept. However, combination of the idea with two-hop based real-time routing protocol could improve both the energy consumption and real-time performance. Hence the idea introduces a newly and challenging area of research. Furthermore, it is expected that this integration improves performance more than the method that only use two-hop neighbor information with fixed transmission power such as THVR. Conversely, increasing transmission power has some disadvantages. This is because as the transmission power increased, the maximum throughput of network will be decrease. This is due to the channel contention and interferences [12]. In the real-time applications the main concern is to meet packet deadline as well as to maximize the total throughput. Moreover performance degradation can be avoided as long as the amount of real-time data is sufficiently small and hence the maximum network capacity is not required. The power control mechanism used in PATH, manages the tradeoff between energy consumption, packet delay and network capacity. In the case that there is no suitable choice for packet forwarding and the delay threshold is small, PATH increases transmission power and improves link quality in order to reduce the packet dropping probability. Conversely when the delay threshold is big, PATH reduces the transmission power for the sake of energy saving.

3. Design goals and motivation of PATH

The main goal of PATH is to increase the number of the packets that can meet their deadline. PATH accomplishes this goal by means of reducing the number of dropped packets in an energy efficient fashion. In SPEED and THVR the main cause of the packet dropping is that there is no eligible forwarding choice in the neighborhood table for packet forwarding. However, in such situations PATH try to discover an eligible forwarding choice with power adaptation scheme. PATH follows these principles:

1. Since real-time applications have different end-to-end requirement, PATH try to provide service differentiation and control tradeoff between energy and delay constraint with dynamic velocity assignment and dynamic power control.
2. PATH should act in a localized manner to scale well to large WSNs and also achieve better real-time performance by using two-hop neighbor information.

In this paper we assume that each node is aware of the locations of both itself and its destination via GPS or other localization scheme [14],[15]. Therefore each node is aware of factors such as node ID, position, remaining energy, transmitting power and etc of its one and two-hop neighbors.

3. Description of path protocol

PATH has three main components which are (1) forwarding metric and policy, (2) delay estimator, (3) power adaptation. The forwarding metric and policy component select one energy efficient path that can provide required delivery velocity at each hop. If forwarding policy cannot find any suitable forwarding node the power adaptation mechanism will be invoked and will adjust transmission power to find an eligible forwarding choice. Delay estimation periodically estimate link delay to update the information that used by forwarding policy. These components will be described in detail in following sections.

3.1 Forwarding metric and policy

As mentioned before PATH maps the problem of meeting end-to-end delay to local problem of providing required velocity at each hop. Let us denote the source and the destination by *S* and *D* respectively. Moreover let *N*(*i*) represents the set of one-hop neighbors of node *i*. $F(i)$ defines the set of one-hop neighbors of *i* which are closer to destination or *i*'s potential one-hop forwarders, $F(i)$ can be written as follow.

$$F(i) \triangleq \{j \mid d(i,D) - d(j,D) > 0, j \in N(i)\} \quad (1)$$

where $d(i,D)$ is the distance between *i* and destination D. Similar to [13], $F_2(i,j)$ is the set of two-hop positional forwarders of node *i* .

$$F_2(i,j) \triangleq \{k \mid d(j,D) - d(k,D) > 0, j \in F(i), k \in N(j)\} \quad (2)$$

The required packet velocity for meeting end-to-end deadline t_{req} is defined by the following equation:

$$S_{req} = \frac{d(S,D)}{t_{req}} \quad (3)$$

Upon receiving the packet, node *i* will calculate the velocity that each two-hop forwarding pairs $\{F(i), F_2(i,j)\}$ can provide. Similar to [9], the following equation defines the velocity that forwarding packet from *i* to *j* and then from *j* to *k* can provide.

$$S_i^{j\to k}(p_i, p_j) = \frac{d(i,D) - d(k,D)}{Delay_i^j(p_i) + Delay_j^k(p_j)} \quad (4)$$

where p_i, p_j are the transmission power of node *i* and node *j* and $Delay_i^j(p_i)$ is the delay for sending a packet from *i* to *j* with power p_i. It is worth pointing out that both the energy that is consumed to forward a packet to the pair of (*j*,*k*) and the remaining energy of two nodes *j* and *k*, have been considered in PATH, whereas in THVR only remaining energy of forwarding choice is considered and energy consumption for forwarding packet is neglected. So we proposed new energy metric in PATH to take into account energy balance throughout the network. This metric is defined as follows.

$$E_i^{j\to k}(p_i, p_j) = \left(\frac{E(p_i)}{E_j} + \frac{E(p_j)}{E_k}\right) \cdot \frac{d(i,D)}{d(i,D) - d(k,D)} \quad (5)$$

where $E_i^{j\to k}(p_i, p_j)$ is the energy consumed to deliver a packet from node *i* to node *k*, having the transmission power of p_i, p_j for node *i* and *j* respectively. $E(p_i)$ is the required energy for forwarding packet with power p_i and E_j is the remaining energy of node *j*. It is also assumed that the initial energy of all the nodes is same.
Finally an original joint metric which considers both delivery velocity and energy consumption defines as follows.

$$ve_i^{j\to k} = C \times \frac{S_i^{j\to k}(p_i,p_j)}{\sum_{(j,k)\in S} S_i^{j\to k}(p_i,p_j)} + (1-C) \times \frac{\frac{1}{E_i^{j\to k}(p_i,p_j)}}{\sum_{(j,k)\in S} \frac{1}{E_i^{j\to k}(p_i,p_j)}} \quad (6)$$

A pair of potential forwarding choices, (*j* , *k*), that has maximum value of $ve_i^{j\to k}$ is selected as forwarding choices. The value of the parameter C, is tuned according to delay requirement of application.

If end-to-end deadline is short and more important than energy efficiency, then the value of *C* has to be larger than $(1-C)$ to emphasis on velocity. However if the end-to-end deadline is sufficiently big, then the value of $(1-C)$ should be greater than C to select more energy efficient path for forwarding. So PATH can control trade of between delay and energy consumption with adapting value of parameter C according to application requirements.

3.2 Power adaptation

Due to the dynamic nature of WSNs, link quality and link delay is highly variable over time [13]. Mobile node and node failure also affected link quality. With respect to these characteristics, protocols like THVR or SPEED can't find suitable forwarding choices in some cases, so they drop packets. However in PATH, an efficient power adaptation schema will be invoked to discover eligible forwarding choices for avoiding packet dropping. Power adaptation mechanism adapts transmission power of neighbors that currently exist in the neighborhood table to improve link quality. Whenever PATH cannot find any two-hop neighbor that can provide required velocity, power adaptation scheme will be invoked to discover neighbors that can achieve higher delivery velocity.

Suppose that node *i* send packets to destination D that there is no eligible forwarding choice that can provide two-hop delivery velocity in its one-hop neighbors. Node *i* initiate power control mechanism with broadcasting Request To Route (RTR) packet with power level P that is greater than previous power level. Some node like *j* that hear the RTR packet, reply with Rout Reply(RR) packet to the *i* if : a) forwarding packets from *i* to *j* makes progress toward destination and b) the delivery velocity that node *j* can provide in two hop is higher than S_{req} . Among all the eligible nodes for power increasing that sends RR packets to node *i*, PATH selects the node *j* that its forwarding metric (formula 6) has the maximum value.

Conversely in the situations that sufficient number of node pairs can provide the required velocity, power adaptation mechanism will decreases the transmission power of most energy efficient pair by linear factor β (β>0) until one of the following conditions are satisfied : (*a*) the minimum power of the node will be reached or (*b*) there are two consecutive power levels that in lower power level the velocity requirement does not satisfied or in the other word by further decreasing the power, the velocity requirement is not satisfied.

3.3 Delay estimation

To estimate the packet delay, we adopt the method of window mean with exponentially weighted moving average (WMEWMA).

$$Delay_i^j(p_i)_{(t+1)} = \alpha M_i^j(t) + \frac{1-\alpha}{T} \sum_{k=max(1,t-T)}^{t-1} Delay_i^j(p_i)_{(k)} \qquad (8)$$

where T is the time window. Moreover the delay of time $t+1$ is computed with respect to delay in time t and the newest measured delay $M_i^j(t)$. If in the network the delay varies highly over time, then parameter α, should be large to emphasis on the newly measured delay. But if in the network that delay variation is small, α can be selected with smaller value.

3.4 Initiative Drop Control

If power adaptation mechanism cannot find new suitable forwarder, the initiative drop controller will be invoked and decide whether the packet should be drop or not. This diction will be made based on the distance that the packet traversed and the miss ratio of the links to the current node's neighbors. Like THVR the forwarding velocity is computed with the following formula:

$$u_i = \begin{cases} 1 - K_1 \frac{\sum_{j=1}^{N} e_j}{N} & \frac{d(i,D)}{d(S,D)} > \frac{1}{2} \\ 1 - K_2 \frac{\sum_{j=1}^{N} e_j}{N} & \frac{d(i,D)}{d(S,D)} < \frac{1}{2} \end{cases} \qquad (9)$$

Where $0 < u_i < 1$ and K_1 and K_2 are proportional gains with $K_1 > K_2 > 0$. As you see when the packet is closer to the destination the forwarding probability is higher than the packets that travel short distance to the destination.

4. Performance evaluation

We implement and evaluate proposed protocol, PATH in prowler [18]. Prowler is a discrete event simulator for simulating wireless network and protocol from radio/Mac layer to application layer. Table describes some parameter setting for simulation.

Table.1 setting parameters

Routing protocol	THVR, PATH
Mac protocol	B-MAC
Bandwidth	915 MHz
Packet size	50 byte
Network area	200*200 meter
Node number	200 node with normal distribution

Mac protocol that is used is CSMA like B-MAC that is commonly used in WSN's. The Mac setting and the energy model that is used in PATH are similar to THVR [9]. We simulate both THVR and PATH protocol and compare PATH with THVR that is the best real-time routing protocol, in terms of real-time performance and energy consumption. Deadline Miss Ratio or DMR is the main factor for comparing real-time performance of routing protocol that is computed by dividing the number of packets that meet deadline requirement to the total number of packets sent.

In the simulation we consider one source in (20m, 20m) and the sink fixed in (200m, 200m). The source sends the packet to the destination with 1packet/s and the size of packet is 50 byte. The parameter C in formula 6 is set to 0.9 for emphasizing in real-time delivery. In the first set of simulation the performance of both protocols is compared for different deadline requirement ranging from 900 ms to 1800 ms. In each run 500 packet are sent to sink. Fig.1 shows that PATH outperforms THVR in term of DMR. In both THVR and PATH as the deadline is increased the DMR is decreased because packets have more time and so more suitable path for reaching destination.

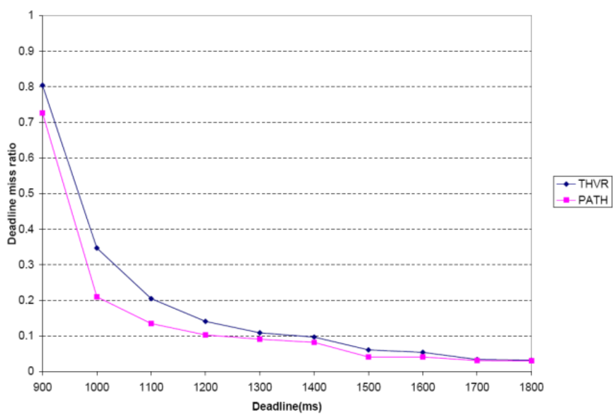

Fig.1 Deadline Miss Ratio comparison of THVR and PATH

The main superiority of PATH over THVR and the main contribution of this protocol is that PATH decreases the probability of packet dropping, using power adaptation mechanism and as a result it decreases the deadline miss ratio of delay sensitive packet. As see in fig.1The improvement of PATH over THVR is more clear in short deadline because in short deadline the probability of packet dropping is high and so the advantage of PATH in decreasing packet dropping is clearer.
Also we compare THVR and PATH with respect to energy consumption. Fig.2 shows that PATH is more energy efficient than THVR.

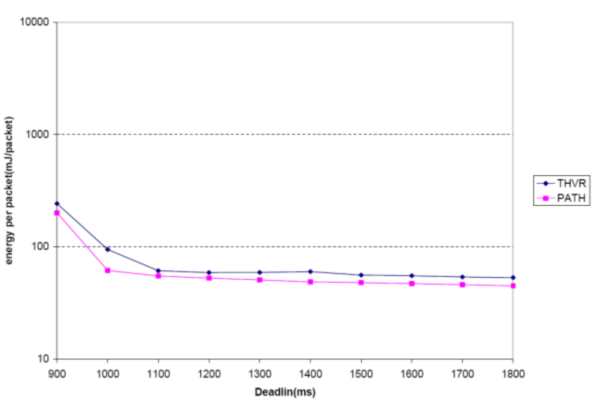

Fig.2 Energy consumption comparison of THVR and PATH

This improvement is due to improvement of DMR in PATH, and also is because of energy metric that PATH is used. THVR energy metric is only based on the remaining energy of forwarding candidate but as mentioned before PATH energy metric take into account both remaining energy of forwarding candidate and energy that is consumed for sending packet to each forwarding choice. So PATH uses energy in an efficient manner than THVR.

5. Conclusion

In this paper a novel real time power aware two-hop (PATH) based protocol is proposed that can improve real time performance in WSNs. The proposed protocol integrates the concept of using two-hop neighbor information with the power control mechanism to archive better real-time performance compared with THVR. This integration reduces the number of packet that cannot meet their delay requirement and so perform better than THVR. Also the reduction of packet dropping concludes in better energy consumption performance. Moreover PATH uses the new energy metric that take into account both energy consumption of path and remaining energy of nodes in path and as a result it balances energy throughout the network effectively and the network lifetime will be increased.

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