PCAR: A Power-Aware Chessboard-Based Adaptive Routing Protocol for Wireless Sensor Networks

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***Abstract*-Increasingly, services operations which perform data sensing and data propagation in a dynamic environment are important tasks of wireless sensor networks. Therefore, increasing the network lifetime is the main contribution of this investigation. In this paper, we propose a novel power-aware chessboard-based adaptive routing (PCAR) protocol to support immobility management in wireless sensor networks. The paramount design challenge in this work is to scale-down network energy consumption, thus maximizing the network lifetime. Our PCAR protocol utilizes vector-oriented propagation, power-consideration decision, and multi-path routing protocols to guide the propagating data to its destination. Moreover, properties of clusters are combined in the PCAR to form cluster-plates in a chessboard-based clustered sensor network. The alternate usage of cluster-head nodes and sleep nodes increases energy efficiency. The opportune divide-and-conquer multi-path fusion mechanism slows down and balances energy consumption. Finally, a performance analysis shows that energy efficiency is achieved by the PCAR protocol.**

I. INTRODUCTION

Due to their small size, low power requirements, as well as programming, computing, communication, distributed sensing capability, and wide sensing applications, *Wireless Sensor Networks* (WSNETs) have recently been investigated [1, 2, 8]. WSNETs continually support services operating in a dynamic environment to perform sensing/propagating tasks, but each sensor node only has a limited energy supply. Data forwarding consumes the largest proportion of energy resources at each sensor node [1]. A number of researchers have widely studied and investigated various energy-saving protocols [2, 6]. Simultaneously, many reports have proposed using single-path routing as compared to multi-path routing for WSNETs. Schurgers *et al.* [2] proposed an energy-efficient protocol which allows nodes to periodically sleep and then wake up to listen for the beacon. Chang and Tassiilas developed a maximum lifetime routing protocol [3] to improve the overall network lifetime, in which every node has a limited lifetime. In addition, Swades *et al.* [7] proposed a novel meshed multi-path routing scheme with selective forwarding of packages to improve the throughput performance over conventional disjoined multi-path routing. When large numbers of sensor nodes are densely deployed, neighboring nodes are usually very close to each other. By collaboration of active neighbor sensor nodes in the coverage region, the cover sensor nodes share the required power for transmission, thus decreasing the throughput and power consumption. Hence, employing alternate or collaborative schemes with each other for querying or data exchange is very useful for increasing the operational lifetime of a network [4, 5]. In this paper, all sensor nodes were considered to be formed and organized into a *chessboard-based* mesh. A novel *power-aware chessboard-based adaptive routing* (PCAR) protocol is proposed to support immobility management in wireless sensor networks. Our PCAR protocol utilizes the properties of clusters are combined in the PCAR to form cluster-plates in the chessboard-based clustered sensor network. The opportune divide-and-conquer multi-path fusion mechanism slows down and balances energy consumption. Finally, a performance analysis confirms that energy efficiency is achieved by the PCAR protocol. The rest of the paper is organized as follows.

In Section 2, the basic ideas and required notations are briefly described. This is followed by a discussion on PCAR schemes in Section 3. In Section 4, the performance evaluation of PCAR schemes is presented. Finally, Section 5 concludes this paper.

II. BASIC IDEAS

This section describes the basic ideas of our developed PCAR (*power-aware chessboard-based adaptive routing*) protocol. The pure shortest-path routing (PSPR) protocol is a well-known WSNET protocol. In traditional PSPR protocols, the massed power consumption of routing along the same paths speedily decreases the energy of the active nodes. Incorrect routing strategies increase power consumption, and our PCAR protocol is designed to avoid wrong decisions in order to extend the lifetime of the network. Our PCAR protocol is performed on a *chessboard-based clustered* mesh. We first define the *basic cluster block.*

Definition 1: Basic cluster block (*BCB*): In the PCAR protocol, a *basic cluster block* (BCB) is a combination of four separate grids and consists of nine nodes. Each grid has four nodes and four contiguous edges. Two adjacent grids have two nodes and one edge in common. If the two-dimensional coordinate of the *center node* (CN) of BCB is (x, y) then the BCB is denoted as β_y^x .

For instance as illustrated in Fig. 1, β_y^x consists of nine sensor nodes, node E is called the *cluster head* (CH), and is in charge of the task of major data flow control. The four cornernodes of β_y^x are *sleep nodes* (SNs), and these normally enter into sleep mode when the center node is active. In addition, the remaining four nodes of β_y^x are *active nodes*, or The cluster nodes and sleep nodes are exchanged periodically to equally share the power consumed by data exchange. The *periodic backbone-path-exchange* scheme is applied to deal with the energy-consumption fairness problem in WSNETs. A common approach for saving power is to allow the active nodes to enter into sleep

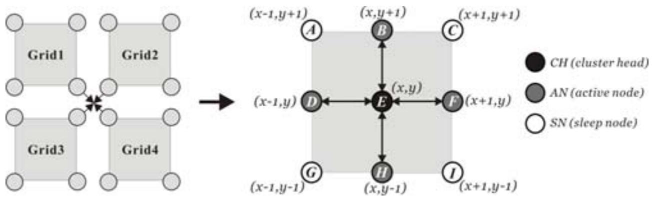

Fig. 1. An example of a basic cluster block, β_y^x .

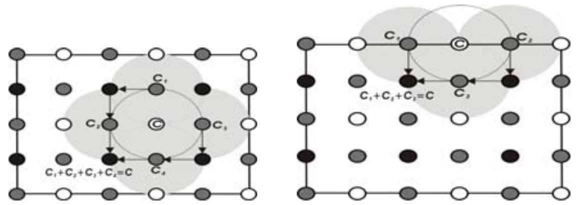

Fig. 2. Examples of data collaboration and fusion

mode if they are not on the routing paths after the sink propagating phase. Without loss of generality, each sensor node of PCAR is assumed to possess a fully functional *global positioning system* (like GPS) receiver, to logically determine its coordinate position and perform a time-synchronization operation. A *chessboard-based clustered* (CBC) mesh consists of many BCBs. Each BCB is surrounded by four cluster blocks, and adjacent BCBs overlap with each other. An overlapping edge has three overlapping nodes. Three overlapping nodes consist of one AN and two SNs. All of the CHs and ANs form the backbone paths of the CBC mesh. In an overall view of the CBC mesh, the grids of the mesh look like a chessboard, with ANs being black squares and SNs white squares. Incidentally, the mesh is called a *chessboard-based clustered mesh* (CBCM) and the backbone paths are called *chessboard-based backbone paths* (CBCBP).

In the PCAR scheme, the destination node is adopted to the target region. The node nearest to the sink is chosen as the representative node. In Salhieh *et al.*'s simulations [8], they found that if the power considerations are added to the routing protocol, then the overall power consumption is much better balanced than it is without taking power into account. So, the remaining energy of all nodes in the possible direction is compared in PCAR schemes. Recently, data fusion has been extensively used for data collection of WSNETs to reduce data traffic and improve the data transfer efficiency. Much research has proven that use of a combining or aggregating method to merge the sensed and received data will improve the energy efficiency. Fusion data are sent to subsequent nodes with no loss of information when the combined action is completed. In addition, the sensor nodes use the data fusion method to compare and modify uncorrelated data measurements. In the PCAR protocol, sensor collaboration and the fusion property are supported in order to reduce energy consumption and improve the lifetime of the network. The number of active nodes in the PCAR protocol is almost two-thirds those of traditional protocols. Because every node remains active for data collection and propagation in the traditional methods, sleeping nodes must be awakened when they are chosen to be members of the source area. In contrast, the sleep nodes of the source area remain asleep in order to save energy in the PCAR protocol. Each cluster head propagates the sink data to all nodes of the same cluster and to every cluster head of neighboring clusters. When the routing paths are constructed, the sensed data still propagate and fuse back to the downlink nodes. The required sensing data of sleep nodes can be coordinated and fused by the neighboring nodes. For example, the required sensing data of central node *C* can be found by nodes C_1, C_2, C_3, and C_4 as shown in Fig. 2a. The required sensing data of edge node *C* can be found by nodes C_1, C_2, and C_3 as shown in Fig. 2b. Because the sensing area of *C* is covered by the sensing areas of C_1, C_2, C_3, and C_4 in Fig. 2a, the required sensing data of *C* are found from the data of C_1, C_2, C_3, and C_4 using the schemes of data collaboration and fusion.

III. PCAR ROUTING PROTOCOL

The greedy method is a well-known strategy to solve some optimization problems in the analysis of algorithms. By the character of the greedy method, for each PCAR propagation decision is a locally optimal one. The locally optimal propagation of the PCAR ultimately adds up to a globally optimal routing. The PCAR protocol is based on the vector-oriented directed data forwarding scheme, and the main challenge is to determine the propagating direction and maintain the shortest possible paths to avoid unnecessary power consumption. Therefore, the decisions for determining the next location and calculating the difference vector are very important in PCAR. The PCAR's routing algorithm is described below. First, the next cluster head is selected; by the difference vector of the current cluster head with the target node. Second, if the next direction is decided, data are forwarded to the next cluster head by the chosen divide-and-conquer routing strategy. Three routing strategies with different consideration, *Random Multi-Path Routing* (RMPR), *Multi-Path-Oriented Routing* (MPOR) and *Power-Oriented Multi-Path Routing* (POMPR) are proposed in the PCAR protocol and described below. The TDMA systems still support the multi-path routing in PCAR's routing strategy. Three routing strategies are described as follows.

A. Random Multi-Path Routing (RMPR)

For the general average property, the RMPR scheme is first proposed. Due to the next direction having been decided, PMPR has only three different routing paths from which to choose. For direct perception through the senses, the PMPR scheme randomly chooses the next routing path. Moreover, the main propagation direction is bounded, and the dynamically randomly chosen interval routing maintains maximum flexibility from the current cluster to the next current cluster. The PMPR scheme consists of the following steps:

Step 1. The next cluster head is decided using the previously decided direction.

Step 2. The forwarding path is randomly chosen from the possible paths: x-axis routing, y-axis routing, or multi-path routing.

Step 3. If the energy of any node on the chosen path is empty, then that path is discarded and another path is chosen.

Step 4. If all possible paths are discarded, then the routing is discarded and the process jumps to Step 7.

Step 5. If the chosen path is a multi-path, then the sink data packages are split into two parts, and data are propagated to the next cluster head along the chosen paths. If the chosen path is a

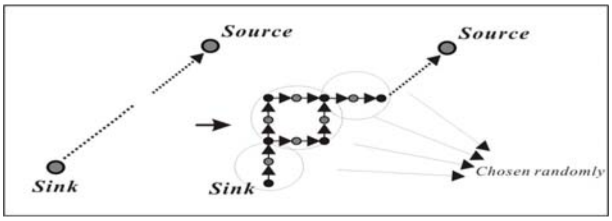

Fig. 3. Strategy for RMPR routing path selection.

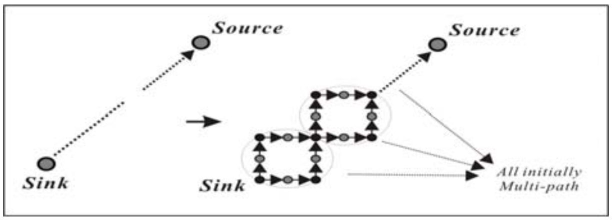

Fig. 4. Strategy for MPOR routing path selection.

single path, then data are propagated to the next cluster head along the single chosen path. The required transfer and receiving power consumption is deduced from the passing nodes.

Step 6. If the target region is reached, then the sink data are propagated to all of the target region's nodes along multi-path routing. Otherwise, the process jumps to Step 1.

Step 7. When sink data are being propagated to the source area, the routing path is constructed. In the source area, active nodes sense and fuse data, then data are propagated back to the previous node by the reversed routing paths. The active nodes in the routing paths fuse, split, and propagate data until the request is completed.

Step 8. The routing protocol is finished.

B. Multi-Path-Oriented Routing (MPOR)

Different from the general average property of PMPR, data sharing is the first issue of the MPOR scheme. To divide the data into multi-path is the first consideration in any MPOR's propagation. In the MPOR, if the powers of the next two path's nodes are sufficient, then the data packages are always divided into two parts by the ratio of the power. Reducing the power consumption of each active node by cooperation is the main issue and contribution of the MPOR scheme. The routing algorithm of MPOR is described here.

Step 1. The next cluster head is determined using the previously decided direction.

Step 2. The next forwarding path from the current cluster head to the next cluster head is determined.

Step 3. If the energy of any node on the multi-path is empty, then the failed path is discarded, and data are propagated using a single path. If one of the multi-paths is discarded, then the process jumps to Step 5. If both paths are discarded, then the routing is discarded and the process jumps to Step 8.

Step 4.The sink data packages are split into two parts, and the next cluster head is propagated along the chosen multi-path route. The required transfer and receiving power consumption is deduced from the passing nodes. The process goes to Step 6.

Step 5. Data are propagated to the next cluster head along a non-empty path.

Step 6.If the target region is reached, then the sink data are propagated to all of the target region's nodes along multi-path routing. Otherwise, the process jumps to Step 1.

Step 7.When the sink data are propagating to the source area, the routing path is constructed. In the source area, the active nodes sense and fuse data, then data are propagated back to the previous node by the reverse routing path. The active nodes in the routing path fuse, split, and propagate data until the request is Step 8.The routing protocol is finished.

C. Power-Oriented Multi-Path Routing (POMPR)

In POMPR, properties of both PMPR and MPOR are adopted, and the power-consideration property is added to POMPR's scheme. Power levels of nodes in multi-path are evaluated and compared. First, POMPR finds the minimum power of nodes along each path. If the minimum power level of neither path is zero ($\forall i = 1,\ldots n,\ R_{xi} \neq 0$ and $R_{yi} \neq 0$) and the minimum power levels of both paths are in the same gap region (gap(n) $\leq$ Min (R_{xi}) , Min(R_{yi}) $\leq$ gap(n+1)) then multi-path routing is adopted. If one of the paths has an empty power node ($\forall i = 1,\ldots n,\ R_{xi} = 0$ or $R_{yi} = 0$) or the minimum power levels of each path are not in the same gap region (gap(i)$\leq$Min(R_{xi}) $\leq$ gap(j) $\leq$ Min(R_{yi}) $\leq$ gap(k) or gap(i) $\leq$ Min(R_{yi}) $\leq$ gap(j) $\leq$ Min(R_{xi})$\leq$gap(k)) then the single path with maximum power is adopted. In POMPR, if the power levels of the next two nodes are sufficient, then data packages are always divided into two parts by the ratio of the power levels, and data are propagated to the next cluster head through multi-path. Reducing the power consumption of each active node by cooperation is the main issue and contribution of the POMPR protocol. The routing algorithm of POMPR is described below.

Step 1.The subsequent cluster head is selected based on the previously decided direction.

Step 2. The Max-Min remainder power levels of the multi-path routing paths are calculated.

M_1 = Min (R_{xi}) and M_2 = Min (R_{yi}), $\forall i = 1,\ldots n$.

M_3 = Max (M_1, M_2).

Step 3. If only $M_1 \leq 0$, then path Rx is discarded and data are propagated using path Ry. For example, if the next CH is in the right, upward direction, then the path moves from β_y^x to β_{y+2}^x . If only $M_2 \leq 0$, then path Ry is discarded, and data are propagated using path Rx. If both M_1 and M_2 are greater than zero and M and M_2 are in the same gap, then data are propagated using multi-path. If both M1 and M2 are greater than zero and M1 and M2 are in different gaps, then are data are propagated using the single path with greater value. If $M_1 \leq 0$ and $M_2 \leq 0$, then the routing is discarded and the process jumps to Step 6.

Step 4. If the chosen paths are multi-path, then the sink data packages are split into two parts. If the chosen path is a single path, then data are propagated to the next CH along the single chosen path. The required transfer and receiving power consumption is deducted from the nodes through which the data pass.

Step 5. If the target region is reached, then the sink data are propagated to all nodes along the multi-path routing and the process jumps to Step 8. Otherwise, the process goes to Step 1.

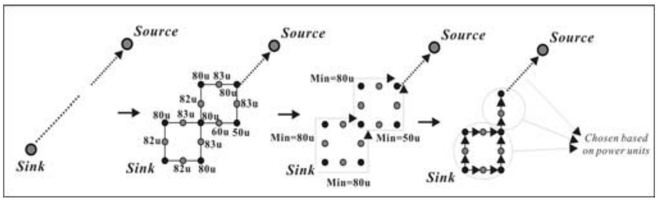

Fig. 5. Strategy for POMPR routing path selection.

Step 6. If all of possible directions are discarded, then the routing is discarded and the process jumps to Step 8.
Step 7. A non-discarded direction is selected and goto Step 2.
Step 8. The routing protocol is finished.

IV. SIMULATION RESULTS

To verify PCAR protocol's analytic observations, some simulations were constructed. Java simulation programs were developed to achieve the PCAR's requirements. A sensor network size of 100×100 was chosen. The nodes of the PCAR's WSNET were arranged and the positions were fixed. The simulations were conducted for 5000, 10,000, 20,000, and 50,000 request messages. The length of the messages was randomly generated, and messages were bound in 200 to 1000 packages. In the traditional PSPR, owing to the repetition of active nodes, the loads of power consumption were located on some fixed active nodes. As a consequence, the miss rate of the PSPR scheme was higher than other schemes. The results of PSPR scheme's simulations showed that if failed nodes grow to 70% than the miss rate will grow to nearly 100%. Because the POMPR scheme is concerned with power policy and locally dynamically decides the routing paths, consequently, the miss rate of the POMPR scheme is lower than those of the PSPR, RMPR, and MPOR schemes. Fig. 6b shows the lifetime curves among PSPR, RMPR, MPOR, and POMPR schemes. Because the PSPR scheme uses fixed routing strategies to propagate data, the routing paths are static, and the lifetimes are limited. Different from the PSPR scheme, PCAR schemes adopt a power-sharing policy and load-balance strategies to dynamically process data propagation. Therefore, the overall lifetimes of PCAR schemes are largely improved over the traditional PSPR scheme. In PCAR schemes, the POMPR schemes use the dynamic routing path to choose strategies to overcome the shortest-path single-direction problem. If the chosen direction has no routing path with sufficient power, then the POMPR scheme permits non-empty and non-backward routing paths to be used. Even if temporary routing paths are adopted, the vector-oriented strategies will guide the next routing path in the correct direction. In a word, POMPR scheme's lifetime is longer than others. Fig. 7a and b show a comparison of four schemes' power states when 10,000 and 20,000 requests were run. Due to the strategy of the dynamic routing path, levels of power consumption of nodes in PCAR schemes are lower and more balanced than those of nodes in PSPR schemes. Consequently, the curves of PCAR schemes in Fig. 7a and b are smoother than the curves of PSPR schemes. Furthermore, the POMPR scheme adopts power-oriented and vector-oriented multi-path routing strategies to overcome the disadvantages of PSPR schemes, so the power efficiency is better than with other schemes.

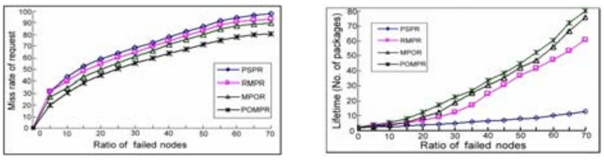

Fig. 6. Performance of miss rate and lifetime curves.

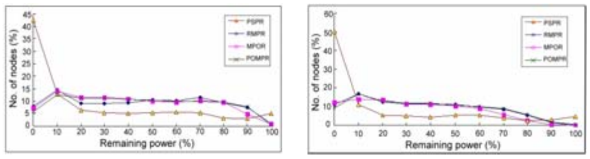

Fig. 7. Power states after 10,000 and 20,000 requests.

V. CONCLUSION

In this paper, we developed the PCAR protocol to integrate vector-oriented propagation and multi-path routing schemes to guide propagating data to its destination. The main design challenges of PCAR schemes are to keep the propagating direction to the shortest possible paths and avoid unnecessary power consumption by active nodes. Simulations showed significant improvements in the data loss rate, power consumption, and network lifetime with this chessboard-based cluster-meshed multi-path routing.

VI. ACKNOWLEDGEMENT

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