Abstract—To reduce energy consumption, in most MAC protocols for wireless sensor networks, listen-sleep cycles are adopted. However, even though it is a good solution for energy efficiency, it may introduce a large end-to-end delay due to sleep delay, since a node with a packet to transmit should wait until the next-hop node of the packet awakes. To resolve this issue, in this paper, we propose the Average Velocity-Based Routing (AVR) protocol for wireless sensor networks that aims at reducing the end-to-end delay. The AVR protocol is a kind of a geographic routing protocol that considers both location of a node and waiting time of a packet at the MAC layer. When a node can use information of \( n \)-hop away neighbor nodes, it calculates the \( n \)-hop average velocity for each of its one-hop neighbor nodes and forwards a packet to the neighbor node that has the highest \( n \)-hop average velocity. Simulation results show that as the knowledge range, \( n \), increases, the average end-to-end delay decreases.

Index Terms—Wireless sensor networks; routing; listen-sleep cycle; low end-to-end delay.

I. INTRODUCTION

In wireless sensor networks (WSNs), energy efficiency is one of the most important issues in developing network protocols. Hence, most MAC protocols for WSNs including famous S-MAC [1] and B-MAC [2] have listen-sleep cycles in which nodes turn its radio transceiver off during sleep states. By introducing sleep periods, nodes can save its energy consumption by reducing idle listening periods. In these protocols, however, a node should wait until the next-hop node wakes up to forward a packet, which is called sleep delay. Hence, even though the listen-sleep cycle is a good solution for the energy efficient MAC protocol, sleep delay is one of its drawbacks, which may cause a large end-to-end delay of a packet. In this paper, we resolve this problem at the network layer by information to the protocol that uses multiple-hop information carefully to improve the performance of the protocol.

In [5], the NADV (normalized advance) routing algorithm is proposed in which the next-hop node is selected based on the NADV that is defined as the forwarding distance to the destination divided by the link cost. This link cost can be either packet error rate, delay, or power consumption of the corresponding link. The NADV protocol shows better performance than basic geographic routing protocols.

In this paper, we develop a routing protocol called the Average Velocity-Based Routing (AVR) protocol that is a geographical routing exploiting the waiting time of a packet at a node to reduce the end-to-end delay. Each node can use information on \( n \)-hop away neighbor nodes. In fact, if \( n = 1 \), our protocol is reduced to the NADV protocol [5]. However, generalizing the NADV protocol that uses one-hop information to the protocol that uses multiple-hop information is not straightforward.

For example, we may think that the negative value of the NADV of each link can be used as the link cost and, then we find the least cost path, i.e., the path that has the maximum value of the sum of NADVs of links on the path, as in traditional routing algorithms. For example, in Fig. 1, \( \text{Dist}(i,j) \) is the distance between nodes \( i \) and \( j \) and \( \text{Wait}(i,j) \) is the waiting time of a packet at node \( i \) from the time the packet arrives at node \( i \) until neighbor node \( j \) receives the packet.

Hence, the NADV between nodes \( i \) and \( j \), \( NADV(i,j) \) is defined as \( NADV(S,1) \approx 3.3 \), \( NADV(1,D) = 6 \), \( NADV(S,2) = 2 \), and \( NADV(2,D) = 10 \). In this example, we can easily know that the optimal path from node \( S \) to node \( D \) that has the minimum end-to-end delay is \( S-1-D \). We now assume that each node can use two-hop NADV’s and simply add NADV’s of two adjacent links. In this case, the sum of NADV’s for path \( S-1-D \) is 9.3 while that for path \( S-2-D \) is 12. Hence, node \( S \) chooses path \( S-2-D \), which provides a longer end-to-end delay than path \( S-1-D \). Hence, we need to use multi-hop information carefully to improve the performance of the protocol.

The rest of this paper is organized as follows. In Section II, we describe our AVR protocol. In Section III, we provide performance evaluations. Finally, we make a conclusion in section IV.

II. AVERAGE VELOCITY-BASED ROUTING PROTOCOL

In this section, we describe the AVR protocol. We assume that the underlying MAC protocol uses listen-sleep cycles. In
addition, we assume that each node knows its location and destination node’s location. We first consider the case when each node uses only one-hop neighbor information. Each node exchanges its location with neighbor nodes via hello messages. Based on the information from its neighbor nodes, each node $i$ calculates the velocity value to each of its neighbor nodes $j$ that indicates how far a packet can be delivered from itself to the direction of the destination per unit time, it the packet is forwarded to node $j$ as

$$V_{avg}^1(i,j) = \frac{Dist(i,D) - Dist(j,D)}{T_{wait}(i,j)},$$

where $D$ is a destination node, $Dist(i,j)$ is the distance from node $i$ to node $j$, and $T_{wait}(i,j)$ is the waiting time of a packet at node $i$ from the time the packet arrives at node $i$ until neighbor node $j$ receives the packet. Hence, the velocity indicates the distance from a sender node to its neighbor node in the direction of the destination divided by sender’s waiting time for delivering a packet to the corresponding neighbor node. Then, node $i$ selects node $j^*$ that has the maximum velocity as its next-hop node for a packet as

$$j^* = \arg \max_{j \in FR_i} \{ V_{avg}^1(i,j) \},$$

where $FR_i$ is the set of neighbor nodes of node $i$. Since each node uses only one-hop information, we call this protocol the one-hop AVR protocol.

We now generalize the one-hop AVR protocol to $n$-hop AVR protocols, in which each node selects the next-hop node by utilizing $n$-hop neighbor nodes’ location and waiting time information ($1 \leq n \leq N$), where $N$ is the number of hops from the node to the destination node. To this end, we first illustrate a two-hop AVR protocol and then, generalize it to an $n$-hop AVR protocol. First, each node $i$ selects one node that has the maximum velocity defined in (1) among the set of one-hop neighbors and sets its one-hop average velocity value, $V_{avg}^1(i)$ and one-hop waiting time $T_{wait}^1(i)$ as

$$V_{avg}^1(i) = V_{avg}^1(i,j^*)$$

and $T_{wait}^1(i) = T_{wait}^1(i,j^*)$,

where $j^*$ is the solution of (2). Then, it broadcasts its one-hop average velocity value, $V_{avg}^1(i)$, and one-hop waiting time $T_{wait}^1(i)$, to its neighbor nodes through hello messages along with its location. After receiving the information from its neighbor nodes, each node $i$ calculates the two-hop average velocity for each of its neighbor node $j$ as

$$V_{avg}^2(i,j) = \begin{cases} (Dist(i,D) - Dist(j,D)) + V_{avg}^1(j)T_{wait}^1(j) \\ T_{wait}^1(j) + T_{wait}^1(j) \\ Dist(i,D) - Dist(j,D)) \\ T_{wait}^1(j) \\ if j \neq D \end{cases},$$

Hence, $V_{avg}^2(i,j)$ is the average two-hop forwarding distance from node $i$ via its neighbor node $j$ to the direction of the destination divided by the total waiting time in those two hops. Based on the two-hop average velocity value in (3), node $i$ determines node $j^*$ to which it has the maximum two-hop average velocity value as its next-hop node as:

$$j^* = \arg \max_{j \in FR_i} \{ V_{avg}^2(i,j) \}.$$  

In a similar way, we can generalize the two-hop AVR protocol to the $n$-hop AVR protocol. We first define the $n$-hop average velocity value of node $i$, $V_{avg}^n(i,j)$, via its neighbor node $j$ as

$$V_{avg}^n(i,j) = \frac{(Dist(i,D) - Dist(j,D)) + V_{avg}^{n-1}(j)T_{wait}^{n-1}(j)}{T_{wait}(i,j) + T_{wait}^{n-1}(j)},$$

where $V_{avg}^{n-1}(j)$ indicates the maximum average velocity value when a data packet moves $(n-1)$-hop to the direction of the destination via node $j$ and $T_{wait}^{n-1}(j)$ is the total cumulative waiting time when a data packet moves $(n-1)$-hop to the direction of the destination via node $j$. Those information can be transmitted from neighbor node $j$ through hello messages. Then, node $i$ selects node $j^*$ to which it has the maximum $n$-hop average velocity value among its neighbor nodes as its next-hop node as

$$j^* = \arg \max_{j \in FR_i} \{ V_{avg}^n(i,j) \}.$$  

### III. PERFORMANCE EVALUATION

In this section, we evaluate the performance of our AVR protocol by using ns-2 [6]. Simulation parameters are summarized in Table I. The AVR protocol operates together with the MAC protocol with listen-sleep cycle. The duty cycle of the MAC protocol is set to 20%. We define the knowledge range as the number of hops that each node can use to calculate the next-hop node. Simulation results show the end-to-end delay performance of the AVR protocol, which is defined as the difference between the time when a packet is transmitted by the source node and the time when it is received by the destination node. For the simulation topology, we use two topologies: grid topology as in Fig. 2 and random topology. In the grid topology, $10 \times 10$ nodes are generated and the distance between adjacent nodes is set to be 25m. There is one destination node at the top right corner and one source node at the bottom left corner. In the random topology, 150 nodes are randomly generated in the 250m by 250m square area with a uniform distribution. A destination node is located at the top right corner of the square and a source node is located at the bottom left corner.

Fig. 3 shows the end-to-end delay performances of NADV and AVR protocols when both protocols use the two-hop knowledge range. In the 2-hop NADV protocol, to determine the next-hop node, each node uses the value that is calculated through the sum of two-hop adjacent links’ NADVs. As shown in this figure, the 2-hop AVR protocol has the better end-to-end delay performance than the 2-hop NADV protocol in both grid and random topologies.
Fig. 2. A 10 × 10 grid topology.

Fig. 3. The comparison of delay performances of NADV and AVR protocols.

Fig. 4. The delay performance of the AVR protocol varying traffic loads in the grid topology.

Fig. 5. The delay performance of the AVR protocol varying the network topology size.

Fig. 6. The delay performance varying traffic loads in the random topology.

Fig. 7. The delay performance of the AVR protocol with a larger knowledge range.

IV. CONCLUSION

In this paper, we propose the Average Velocity-Based Routing (AVR) protocol for wireless sensor networks that considers both waiting time at the MAC layer and location of the node to reduce the end-to-end latency. Each node decides the next-hop node to transfer a packet based on the n-hop average velocity value that is calculated based on n-hop information. Simulation results show that as the number of hops that can be considered increases, the end-to-end delay gets smaller and smaller.

REFERENCES


