HVE-Mobicast: A Hierarchical-Variant-Egg-Based Mobicast Routing Protocol for Wireless Sensornets

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***Abstract*— In this paper, we propose a new mobicast routing protocol, called the HVE-mobicast (hierarchical-variant-egg-based mobicast) routing protocol, in wireless sensor networks (WSNs). Existing protocols for a spatiotemporal variant of the multicast protocol called a "mobicast" were designed to support a forwarding zone that moves at a constant velocity, $\overrightarrow{v}$, through sensornets. The spatiotemporal characteristic of a mobicast is to forward a mobicast message to all sensor nodes that are present at time t in some geographic zone (called the forwarding zone), Z, where both the location and shape of the forwarding zone are a function of time over some interval (t_{start}, t_{end}). Mobicast routing protocols aim to provide reliable and just-in-time message delivery for mobile sink nodes. The new HVE-mobicast routing protocol is a cluster-based VE-mobicast routing protocol. The message delivery of nodes in the forwarding zone of the HVE-mobicast routing protocol is transmitted by two phase: cluster-to-cluster and cluster-to-node phases. In the cluster-to-cluster phase, the cluster-head and relay nodes are distributively notified to wake them up. In the cluster-to-node phase, all member nodes are then notified to wake up by cluster-head nodes according to the estimated arrival time of the delivery zone. The key contribution of the HVE-mobicast routing protocol is that it is more power efficient. This effect is mainly achieved by improving the predicted accuracy, especially by considering different moving speeds and directions. Finally, simulation results illustrate performance enhancements in message overhead, power consumption, and predicted accuracy, compared to existing mobicast routing protocols.**

I. INTRODUCTION

A wireless sensor network is composed of a large number of small-sized, low-cost, low-power wireless sensor nodes/devices. Each sensor node/device has sensing, communicating, and data processing capabilities. One important research issue is the development of power-saving techniques to extend the network lifetime for WSNs with limited energy and scarce resources. Existing power-aware routing protocols are summarized as follows. Youssef *et al* . [7] proposed a constrained shortest-path energy-aware routing protocol with better end-to-end delay and throughput to minimize energy consumption. In addition, multicasting in WSNs is a fundamental and important communication pattern to provide a sink node which can collect aggregated data from a set of sensor/destination nodes. Recently, a new spatiotemporal multicast protocol, namely a mobicast, was presented in WSNs. The spatiotemporal characteristic of a mobicast is to forward a message to all nodes that will be present at time *t* in the forwarding zone, Z. The location and shape of the forwarding zone are a function of time over some interval (t_{start}, t_{end}). The mobicast is constructed by a series of message forwarding zones over different intervals (t_{start}, t_{end}). The sensor nodes in the forwarding zone in the time interval (t_{start}, t_{end}) are woken up for power-saving purposes. Huang *et al*. [3] initially designed a just-in-time multicast protocol for wireless sensor networks under spatiotemporal constraints. Huang *et al*. [4] proposed a reliable mobicast via face-aware routing (FAR) in wireless sensor networks. More recently, Chen *et al*. [2] proposed a variant-egg(VE)-based mobicast routing protocol in sensornets. The VE-mobicast protocol can adaptively and efficiently determine the location and shape of the message forwarding zone in order to maintain the same number of waken-up sensor nodes. According to the factors of the moving speed and direction of movement, the VE-mobicast protocol can improve the prediction accuracy of the forwarding zone. However, the message delivery method of a VE-mobicast is node oriented. This method is not sufficiently efficient and wastes unnecessary energy. In existing protocols, when the prediction of the path of a forwarding zone is inaccurate, the nodes that were woken up earlier in the forwarding zone also waste much energy. It is evident that the cluster-based approach offers benefits of power saves and low packet overhead. Many routing protocols are cluster-based schemes [1][8], since only the cluster head is responsible for forwarding aggregated data. For example, Yu *et al.* [8] presented a clustering scheme for mobile ad hoc networks. Balakrishnan *et al*. [1] proposed an energy-efficient communication protocol for wireless microsensor networks. This protocol uses a cluster-based approach to achieve the purpose of saving power. In this paper, we propose a new mobicast routing protocol, called an HVE-mobicast routing protocol, in wireless sensor networks. The key contribution of the HVE-mobicast routing protocol is that it is a more power-efficient mobicast routing protocol. This purpose is mainly achieved by improving the predicted accuracy, especially by considering different moving speeds and directions.

The rest of this paper is organized as follows. Section 2 presents the basic ideas and challenges of our routing protocol. Our proposed HVE-mobicast protocol is presented in Section 3. Section 4 gives the performance analysis. Finally, Section 5 concludes this paper.

II. BASIC IDEAS AND CHALLENGES

This section discusses the basic ideas and challenges of a special case of a spatiotemporal multicast protocol, called a

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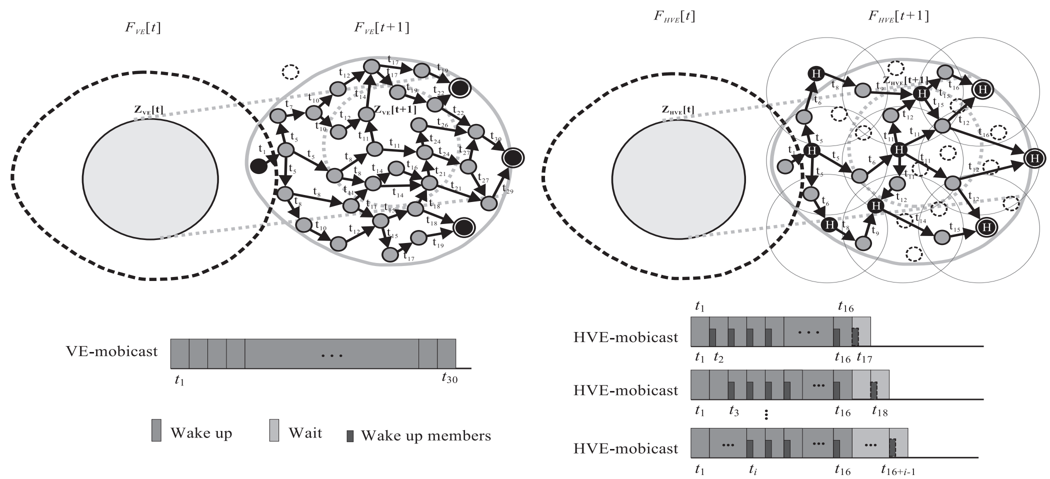

(a) (b)

Fig. 1. Waking up process with the VE-mobicast and HVE-mobicast protocol.

mobicast. A spatiotemporal multicast session is specified by $< m, Z[t], T_s, T >$, which is formally defined in [3] , where m is the multicast message, $Z[t]$ describes the expected area of message delivery at time t, and T_s and T are the sending time and duration of the multicast session, respectively. In general, a mobicast routing protocol is composed of a delivery zone and a forwarding zone. The forwarding zone is defined as every sensor node in forwarding zone $F[t+1]$ being responsible for forwarding the mobicast messages to guarantee that delivery zone $Z[t+1]$ at time $t+1$ can successfully receive the mobicast message. The size of forwarding zone $F[t+1]$ is always larger than the size of delivery zone $Z[t+1]$. One key problem of the mobicast routing protocol is how to predict and estimate the correct size and shape of forwarding zone $F[t+1]$ at time t.

More recently, Chen *et al*. [2] proposed a variant-egg-based mobicast routing protocol. The VE-mobicast routing protocol develops an adaptive shape for the forwarding zone. This adaptive shape of can improve the predicting accuracy of the delivery zone. An example of a VE-mobicast routing protocol is given in Fig. 1(a). The forwarding zone and delivery zone of VE-mobicast routing protocol are denoted as $F_{VE}[t]$ and $Z_{VE}[t]$ at time t. In the VE-mobicast routing protocol, the mobicast message floods the forwarding zone, $F_{VE}[t]$, at time t. The mobicast message also contains information on the direction and speed of the delivery zone. One main purpose of the mobicast message is to adaptively and efficiently determine the location and shape of forwarding zone $F_{VE}[t+1]$ at time $t+1$. Observe that the message delivery mechanism of the VE-mobicast adopts node-to-node transmission.

This paper mainly develops a cluster-based mobicast routing protocol, called the HVE-mobicast routing protocol. The forwarding zone and delivery zone of the HVE-mobicast routing protocol are denoted as $F_{HVE}[t]$ and $Z_{HVE}[t]$ at time t. Forwarding zone $F_{HVE}[t]$ is divided into a set of clusters, where all clusters form the forwarding zone, $F_{HVE}[t]$. The cluster-head elective algorithm can be used from [6]. Therefore, all sensor nodes in $F_{HVE}[t]$ can be classified into groups I and II. Group I contains cluster-head nodes and gateway nodes, while group II contains all other sensor nodes. All sensor nodes of groups I and II are in the forwarding zone. All sensor nodes in group I are initially woken up, and then all sensor nodes in group II are woken up after waiting for a period of time. As shown in Fig. 1(b), the HVE-mobicast routing protocol save power since the power consumption is lower during this period of time for all sensor nodes in group II.

The wake-up time-interval of the VE-mobicast routing protocol is denoted $T_{F_{VE}}$ in which all sensor nodes in $F_{VE}[t+1]$ are woken up. The wake-up time-interval of the HVE-mobicast routing protocol is denoted $T_{F_{HVE}} = T^{I}_{F_{HVE}} + T^{II}_{F_{HVE}}$ in which all sensor nodes in $F_{HVE}[t+1]$ are woken up. Let $T^{I}_{F_{HVE}}$ and $T^{II}_{F_{HVE}} = t_{i-1}$, where $1 \leq i < T_{F_{VE}} - T^{I}_{F_{HVE}}$, denote the time cost to wake up sensor nodes of groups I and II in $F_{HVE}[t+1]$, respectively. Observe that $T^{I}_{F_{HVE}} + T^{II}_{F_{HVE}} < T_{F_{VE}}$, since the cluster advantage is used in the HVE-mobicast routing protocol.

Existing mobicast routing protocols are considered a ”constant velocity mobile mobicast”. For example, using VE-mobicast routing, the moving speed of delivery zones from $Z_{VE}[t]$ to $Z_{VE}[t+1]$ is fixed as a constant velocity $\overrightarrow{v}$. As shown in Fig. 2 (a), all sensor nodes in $F_{VE}[t+1]$ must be woken up before $T_{F_{VE}}$. However, if the moving speed is changed to $\overrightarrow{v'}$, where $|v'| > |v|$, then the delivery zone is moved from $Z_{VE}[t]$ to $Z'_{VE}[t+1]$ from time t to time $t+1$. Assume that the arrival times with $Z_{VE}[t+1]$ of velocities $\overrightarrow{v}$ and $\overrightarrow{v'}$ are t_α and t_β. This resulting $t_\beta < T_{F_{VE}} < t_\alpha$. It thus takes less time to move from $Z_{VE}[t]$ to $Z_{VE}[t+1]$, and not all sensor nodes in $F_{VE}[t+1]$ can be woken up in time before $T_{F_{VE}}$. This causes an error condition in which inaccurate sensing data for the VE-mobicast routing are collected if a variable speed for the delivery zone is considered. This condition can efficiently be improved by using HVE-mobicast routing protocol, since $T_{F_{HVE}} < T_{F_{VE}}$. As illustrated in Fig. 2(b), assume that the arrival times of $Z_{HVE}[t+1]$ with velocities $\overrightarrow{v}$ and $\overrightarrow{v'}$ are t_α and t_β. Our scheme works well when $T_{F_{HVE}} < t_\beta < t_\alpha$ and $T_{F_{HVE}} < t_\beta < T_{F_{VE}}$.

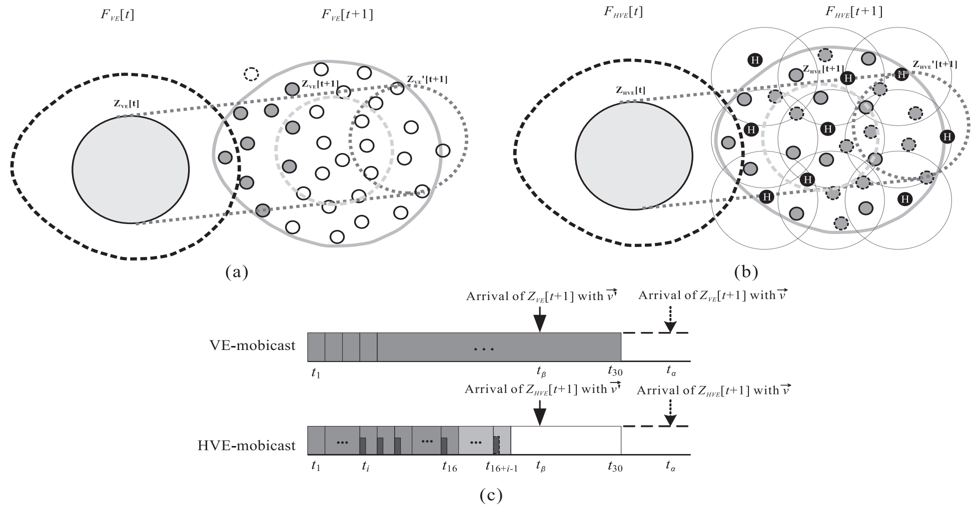

Fig. 2. Delivery zone with high speed in the VE-mobicast and HVE-mobicast protocols.

III. HVE-MOBICAST: HIERARCHICAL-VARIANT-EGG-BASED MOBICAST ROUTING PROTOCOL

In this section, we present the hierarchical variant-egg-based mobicast routing protocol. In this work, each node is assumed to be equipped with a location provider (*global position system,* GPS), and a cluster environment is pre-constructed as described in [8] before applying the HVE-mobicast routing protocol. The HVE-mobicast routing protocol is divided into two phases as follows.

A. Phase I: Egg Estimation

All sensor nodes in $H_{HVE}[t]$ at time t estimate the shape and size of variant-egg $F_{HVE}[t+1]$ for the incoming delivery zone, $Z_{HVE}[t+1]$. The shape of the variant-egg is calculated by the equation of the *Cassini Oval* [5]. The equation can be reduced to:

$$[(x)^2 + (y)^2]^2 - 2e^2[(x)^2 - (y)^2] = 0$$

The detailed formula of the variant-egg can be seen in [2]. Fig. 3 shows an example of $F_{HVE}[t+1]$, where O_1 and O_2 denote two fixed points, O_2 is the center of the variant-egg forwarding zones, and $e = \pi^{1/2}R$. The term, R, is the radius of delivery zone, D is the distance between delivery zone and forwarding zone, and r is the radius of the cluster. One important task is deciding whether or not a sensor node (a, b) is located in a variant-egg forwarding zone. If $(x^2+y^2)^2 - 2e^2(x^2-y^2) = (a^2+b^2)^2 - 2e^2(a^2-b^2) \leq 0$, then (a, b) is located in variant-egg forwarding zone. If $(x^2+y^2)^2 - 2e^2(x^2-y^2) = (a^2+b^2)^2 - 2e^2(a^2-b^2) > 0$, then (a, b) is not located in variant-egg forwarding zone $F_{HVE}[t+1]$. Given $F_{HVE}[t] = (x_t^2+y_t^2)^2 - 2e_t^2(x_t^2-y_t^2)$ and $F_{HVE}[t+1] = (x_{t+1}^2+y_{t+1}^2)^2 - 2e_{t+1}^2(x_{t+1}^2-y_{t+1}^2)$, an estimated hop count, H, is estimated as follows.

S1: The first task is to decide whether or not sensor node P_1 at (a, b) is located in the hold-and-forward zone $H_{HVE}[t] = F_{HVE}[t] \bigcap F_{HVE}[t+1]$. Sensor node P_1 is within $H_{HVE}[t]$ if P_1 is within $F_{HVE}[t]$ and P_1 is also within $F_{HVE}[t+1]$; that is, $(x_t^2+y_t^2)^2 - 2e_t^2(x_t^2-y_t^2) = (a^2+b^2)^2 - 2e^2(a^2-b^2) \leq 0$ and $(x_{t+1}^2+y_{t+1}^2)^2 - 2e_{t+1}^2(x_{t+1}^2-y_{t+1}^2) = (a^2+b^2)^2 - 2e_{t+1}^2(a^2-b^2) \leq 0$.

S2: An estimated hop count, H, is roughly calculated as follows. This estimated value is useful in phase II. Assume that a cluster covers the region of $H_{HVE}[t]$ which is called the *hold-and-forward cluster.* Let P_1 in $H_{HVE}[t]$ be a *hold-and-forward cluster head*. Given any relay node, P_2, path $\overleftrightarrow{P_1P_2}$ from P_1 to P_2 is considered, where point P_3 is the intersection of path $\overleftrightarrow{P_1P_2}$ with $F_{HVE}[t+1]$.

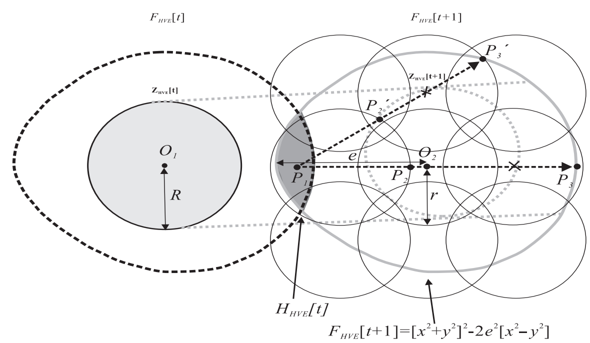

Fig. 3. Definition of the HVE-mobicast.

B. Phase II: Distributed Hierarchical-Variant-Egg-based Mobicast

In phase II, we develop a distributed algorithm based on a cluster approach to dynamically adjust the size and shape of variant-egg-based $F_{HVE}[t+1]$. The sensor nodes in $H_{HVE}[t]$ should forward a mobicast message to the *hold-and-forward* cluster head. Then, the *hold-and-forward* cluster head forwards the mobicast message to all other clusters in $F_{HVE}[t+1]$ to first wake up all sensor nodes in group I, and then wake up all other sensor nodes in group II after a calculated time. As mentioned before, all sensor nodes are divided into two groups; group I consists of cluster head nodes and relay nodes, while all other sensor nodes (member nodes in all clusters) are in group II. None of the nodes in group II relays flooding

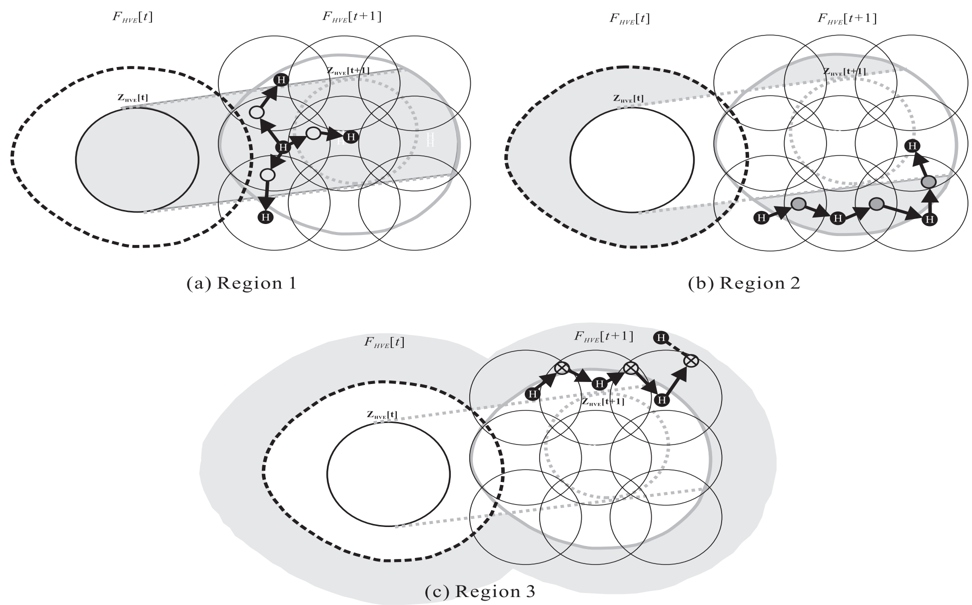

Fig. 4. Forwarding rules for relay nodes in three different regions.

packets. This results in low packet overhead.

A simple control packet, denoted P_{HVE} or $P_{HVE}(\frac{h}{H}, N_{11}N_{12}...N_{1i})t_x$, is adopted in this work for developing the distributed algorithm, where $\frac{h}{H}$ is used to limit the number of packets forwarded, $N_{11}N_{12}...N_{1i}$ keeps the path history, and the P_{HVE} packet is forwarded at time t_x. The value of H is calculated by $\lceil \frac{\overline{P_2P_3}}{r} + 1 \rceil$ from phase I, and the term, h, is increased if a P_{HVE} packet travels from one cluster to another cluster. Assume that all sensor nodes are uniformly distributed in an area. This area is divided into three kinds of regions. Without loss of generality, we only consider the case of $Z_{HVE}[t]$ being adjacent to $Z_{HVE}[t+1]$, and a pair of $F_{HVE}[t]$ and $F_{HVE}[t+1]$ to explain the three regions.

- Region 1: A region along a path from $Z_{HVE}[t]$ to $Z_{HVE}[t+1]$, as shown in Fig. 4(a).
- Region 2: $F_{HVE}[t] \bigcup F_{HVE}[t+1]-$ Region 1, as illustrated in Fig. 4 (b).
- Region 3: $\sim (F_{HVE}[t] \bigcup F_{HVE}[t+1])$, as illustrated in Fig. 4 (b).

The distributed algorithm of the HVE-mobicast operation is given here; steps **S1-S5** attempt to wake up all sensor nodes in group I, whole steps **S6** and **S7** are used to wake up all sensor nodes in group II.

S1: Sensor nodes in $H_{HVE}[t]$ forward a mobicast message to the *hold-and-forward* cluster head at time t_1. Then, the *hold-and-forward* cluster head forwards the mobicast message to all neighboring cluster head nodes. Only cluster head P_i initiates and floods $P_{HVE}(\frac{1}{H}, P_i)t_x$ packets through relay nodes to neighboring cluster head P_j at time t_y, where H is the hop count calculated in phase I, $t_y = t_x + d + backoff\_time$, and d is the degree (number of neighboring relay nodes) of P_j.

S2: Let cluster head H receive the $P_{HVE}(\frac{h_1}{H_1}, N_{1,1}N_{1,2}...N_{1,i-1})t'_{x_1}$ packet from N_{1i-1} at time t'_{x_1}, where $t'_y = t'_{x_1} + d + backoff\_time$ and d is number of neighboring relay nodes of H. Cluster head H waits for a period of time until t'_y to receive any additional different P_{HVE} packets. A *waiting timer*, T_w, is set up, and this waiting timer is used to wake up all member nodes in the cluster before the arrival of $Z_{HVE}[t+1]$, where *waiting timer* $T_w = T' - T''$, for which T' is the estimated arrival time of delivery zone $Z_{HVE}[t+1]$, and T'' is the minimum time which cluster head H receives the mobicast message.

S3: If relay node R receives the mobicast message, it is not forwarded to the next cluster head, H, if R and H are both in region 3.

S4: Assume that $P_{HVE}(\frac{h_1}{H_1}, N_{1,1}N_{1,2}...N_{1,i-1})t'_{x_1}$, $P_{HVE}(\frac{h_2}{H_2}, N_{2,1}N_{2,2}...N_{2,i-1})t'_{x_2}$,..., and $P_{HVE}(\frac{h_m}{H_m}, N_{m,1}\ \ N_{m,2}\ \ ...N_{m,i-1})t'_{x_m}$ packets are received at cluster head H before time t'_y, and m P_{HVE} packets are merged to one P_{HVE} packet, denoted as $P_{HVE}(\frac{h_{merge}}{H_{merge}}, \begin{bmatrix} N_{1,1}N_{1,2}...N_{1,i-1}, P_i \\ \vdots \\ N_{m,1}N_{m,2}...N_{m,i-1}, P_i \end{bmatrix})_{t'_y}$. The merging operation, which depends on the position of cluster head H, is given here.

1. Let $\frac{h_{merge}}{H_{merge}} = \frac{\underset{1 \le i \le m}{Min h_i}}{\underset{1 \le i \le m}{Max H_i}}$ if H is in region 1.
2. Let $\frac{h_{merge}}{H_{merge}} = \frac{\underset{1 \le i \le m}{Min h_i}}{\underset{1 \le i \le m}{Min H_i}}$ if H is in region 1.
3. Let $\frac{h_{merge}}{H_{merge}} = \frac{\underset{1 \le i \le m}{Max h_i}}{\underset{1 \le i \le m}{Min H_i}}$ if H is in region 1.

Examples of the merging operation in step **S4** are shown in Fig. 5.

S5: If there are n identical predecessor cluster heads

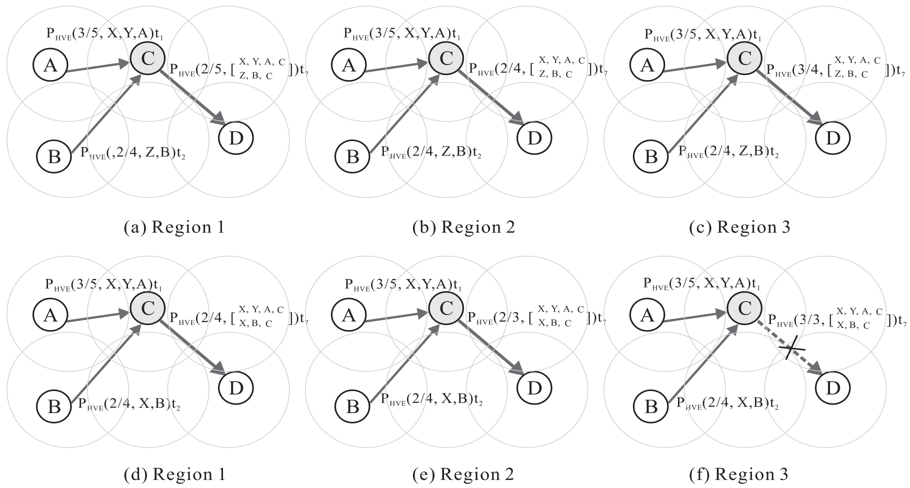

Fig. 5. Merging operations for cluster heads.

for all path histories of $\begin{bmatrix} N_{1,1}N_{1,2}...N_{1,i-1}, P_i \\ \vdots \\ N_{m,1}N_{m,2}...N_{m,i-1}, P_i \end{bmatrix}$, then let $H_{merge} = H_{merge} - n$. After that, the $P_{HVE}(\frac{h_{merge}}{H_{merge}}, \begin{bmatrix} N_{1,1}N_{1,2}...N_{1,i-1}, P_i \\ \vdots \\ N_{m,1}N_{m,2}...N_{m,i-1}, P_i \end{bmatrix})\ t'_y$ packet is forwarded if $\frac{h_{merge}}{H_{merge}} < 1$ at time t'_y.

In step **S5**, it can be observed that $\frac{h_{merge}}{H_{merge}}$ is used to determine whether or not the P_{HVE} packet should be forwarded by the cluster heads, where h_{merge} denotes the estimated hop number over which the current P_{HVE} packet traverses and H_{merge} is the estimated hop count toward the boundary of $F_{HVE}[t+1]$. If the ratio of $\frac{h_{merge}}{H_{merge}} < 1$, the P_{HVE} packet should be forwarded since $h_{merge} < H_{merge}$. If the ratio of $\frac{h_{merge}}{H_{merge}} \geq 1$, the P_{HVE} packet can be forwarded since $h_{merge} \geq H_{merge}$.

S6: Each cluster head maintains a *waiting timer*, T_w, then all sensor nodes in group II are woken up by the cluster head if $T_w \leq 0$. Let *waiting timer* $T_w = T' - T''$, where T' is the estimated arrival time of delivery zone $Z_{HVE}[t+1]$, and T'' is the minimum time when cluster head H receives the mobicast message.

S7: In the beginning, the sensor nodes in $H_{HVE}[t]$ send a control signal to the cluster head of the *hold-and-forward* cluster at time t_1. The control signal, $P'_{HVE}((a_0, b_0), \overrightarrow{v})$, consists of the initial position (a_0, b_0), and the moving speed and direction $\overrightarrow{v}$ of $Z_{HVE}[t]$. The nodes of group I in $H_{HVE}[t]$ periodically check the moving speed and direction of $Z_{HVE}[t]$.

IV. PERFORMANCE ANALYSIS AND COMPARISON RESULTS

In this section, we evaluate the performance of the HVE-mobicast routing protocol through our developed Java program. To examine the effectiveness of our approach, three routing protocols, termed the Mobicast [3], FAR [4], and VE-Mobicast [2], are compared with our HVE-mobicast routing protocol. The simulations were carried out for in nine different areas, $1000 \times 400m^2, 1000 \times 500m^2, 1000 \times 600m^2, 1000 \times 700m^2, 1000 \times 800m^2, 1000 \times 900m^2, 1000 \times 1000m^2, 1000 \times 1100m^2, and 1000 \times 1200m^2$ with 800 sensor nodes which were set up at random. The communication radius of the sensor node is 35 m. The spatiotemporal application periodically broadcasts a mobicast message let the sensor nodes know the position with a 1-s period. The delivery zone where the spatiotemporal application takes place is circular, the velocity is 40 m/s, and the radius is 45 m. The communication radius of the cluster is 35 m. Assume that the consumption of power is denoted as *n* (in Watts; W). If the sensor node stays in the sleeping mode, then n=1; if the sensor node stays in the active mode then n=5; if the sensor node transmits a mobicast message then n=10.

We analyzed all simulated data of *packet overhead* (PO), *power consumption* (PC), *needlessly woken-up nodes* (NWNs), and the *successfully woken-up ratio* (SWR) from all sensor nodes in the sensornet. The performance metrics are defined as follows.

- *Packet overhead* (PO): The total number of packets that every sensor node transmits, including the control and mobicast message.
- *Power consumption* (PC): The total power for all sensor nodes consumed for every simulation.
- *Needlessly woken-up nodes* (NWNs): The number of woken-up nodes in the forwarding zone through which the delivery zone did not pass.
- *Successfully woken-up ratio* (SWR): The number of woken-up nodes in $F_{HVE}[t+1]$ divided by the number of nodes which should have been woken up in $F_{HVE}[t+1]$.

A. Packet overhead *vs.* rotation angle

Fig. 6 shows the results of the packet overhead (PO). In the HVE-mobicast routing protocol, only the nodes of group I are involved with message routing instead of all nodes. Due to the hierarchical structure, the HVE-mobicast routing protocol can greatly reduce the message overhead. The PO of the HVE-mobicast is lower than that of the other routing protocols.

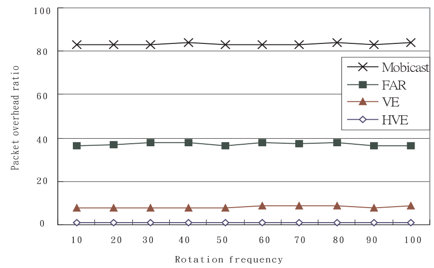

Fig. 6. The packet overhead ratio vs. the rotation frequency.

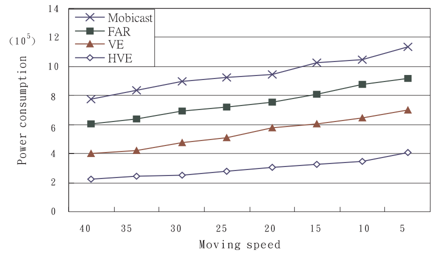

Fig. 8. Power consumption (PC) vs. the moving speed.

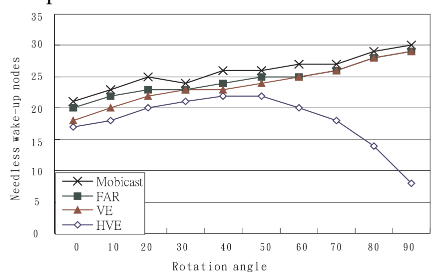

Fig. 7. Needless wake-up nodes vs. Rotation angle

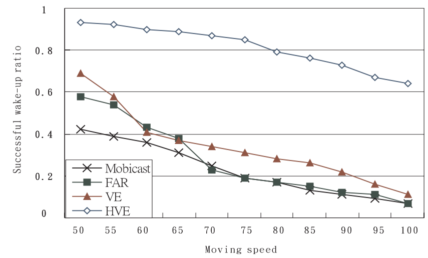

Fig. 9. The successfully woken-up ratio v.s. moving speed.

B. Needlessly woken-up nodes *vs. the* rotation angle

Fig. 7 shows the results of the needlessly woken-up nodes (NWNs). The HVE-mobicast routing protocol resends control packets *P'* to inform cluster heads in the forwarding zone when the moving direction of the delivery zone changes. The cluster heads that receives the control packets stop the *waiting timer* so as to prevent nodes of group II from being woken up. Then the cluster heads go back to sleep. The HVE-mobicast routing protocol reduces the NWNs due to its hierarchical structure and the mechanism of the *waiting timer*.

C. Power consumption *vs.* moving speed

Fig. 8 shows the results of power consumption (PC). When the moving speed of the delivery zone suddenly decreases, the woken-up nodes in the forwarding zone have to wait for a long time until the arrival of the delivery zone. This consumes more power than with a fixed moving speed. The PC of the HVE-mobicast routing protocol slowly increases because of the mechanism of the *waiting timer*. The cluster heads adjust the waiting timer to wake up the nodes of group II late in order to save power.

D. Successful woken-up ratio *vs.* moving speed

Fig. 9 shows for the successfully woken-up ratio (SWR) of the HVE-mobicast was higher than those of the Mobicast, FAR, and VE-mobicast protocols. Because the method of waking up nodes in these three routing protocols is node-by-node, it is inefficient. The HVE-mobicast routing protocol wakes up the nodes in group I in a very short time. The HVE-mobicast resends control signal *P'* to adjust the *waiting timer* to wake up nodes of group II early. Therefore, the HVE-mobicast routing protocol achieves a high SWR.

V. Conclusion

In this paper, we present a new mobicast routing protocol, called the Hierarchical-Variant-Egg-based Mobicast (HVE-mobicast) routing protocol, to improve the efficiency of message delivery in wireless sensor networks. The method of message delivery in the HVE-mobicast routing protocol is handled cluster-by-cluster instead of node-by-node. Based on the hierarchical cluster structure, the contributions of our HVE-mobicast routing protocol are summarized as follows; (1) due to the method of message delivery, our HVE-mobicast routing protocol adapts to the dynamically changing moving speed of the delivery zone, (2) by utilizing the variant-egg shape of the forwarding zone, our HVE-mobicast routing protocol adaptively and efficiently determines the location and shape of the forwarding zone to achieve high predicted accuracy, and (3) when the prediction of the path of forwarding zone is inaccurate, our HVE-mobicast wastes less energy than the other existing protocols.

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