Chapter 12: Mobicast Routing Protocol in Wireless Sensor Networks

Prof. Yuh-Shyan Chen
Department of Computer Science and Information Engineering
National Taipei University
Jan. 2008
Outline

1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
   1. ACM Wireless Network, 2006
   2. IEEE ICC, Korea, 2005
4. Our HVE-mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
Outline

1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
   1. ACM Wireless Network, 2006
   2. IEEE ICC, Korea, 2005
4. Our HVE-mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
In this talk, we consider a new “mobicast” routing protocol in the wireless sensornets.

- A spatiotemporal variant of multicast called a “mobicast” were designed to support a forwarding zone that moves at a constant velocity, \( v \), in sensornets.

- This spatiotemporal multicast protocol provides sensing applications that need to transfer the multicast message to the “right” place at the “right” time.
Mobicast framework
Mobicast applications

soldier
Our Mobile-Sink Implementation
Motes

Smart Dust Sensors, Wireless Sensor Networks

(http://www.xbow.com/)
Mote Kits
MTS101 – Basic Sensor Module
MICA2DOT Multi-Sensor Module (MTS510)
MICAz - 2.4 GHz IEEE 804.15.4/ZigBee™ Compliant Mote
Our Implementation
多媒體無線行動感測車
MEP410CA– Micro Climate Multi-Sensor Node
Gateway & Network Interface Modules

- **Stargate** - XScale Network Interface and Single Board Computer
Mobicast framework
Key problem: “hole” problem
Outline

1. Introduction
2. Related works
3. Our mobicast routing protocol
   1. ACM Wireless Network (accepted)
   2. IEEE ICC, Korea, 2005
4. Our enhanced mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
Related Works

- **Multicast**

- **Geocasting**

- **Mobicasting**

- Geocasting: the group consist of the set of all nodes within a specified geographical region

- A Spatiotemporal multicast protocols for sensornets
  - A new multicast routing protocol
    - Multicast message be disseminated to the “right-place” at the “right-time”
  - A special class of spatiotemporal multicast
    - Mobicast routing protocol
      - A delivery zone that translates through a 2-D space at some constant velocity
- Centralized Algorithm
Simple Mobicast Solutions

- Hold-and-Forward
  - Only nodes on the path of the delivery zone will participate.
  - Delivery-Zone-constrained (DZC) protocol
DZC Protocol Cannot Guarantee Delivery

Problem: how to determine who should participate without knowing the detail of the global network topology?
A Reliable Mobicat Protocol

- **Forward-Zone Constrained (FZC)**
  - Only nodes in the path of the forwarding zone will participate in the mobicast forwarding.

Spatial and Connectivity Configuration of the Network Influence the Size of forwarding Zone

- The value of compactness is estimated under a local environment
  - Local compactness
  - Reduce message overhead
  - Distributed algorithm but is un-reliable
Huang et al., “**Reliable Mobicast via Face Aware Routing**”, IEEE INFOCOM, March 2004.

- Reach reliable mobicast delivery
  - Using information form a sensor node’s immediate **spatial neighborhood**
  - Forwarding schedule depends on local topology information.
    - **Right-hand neighborhood discovery protocol**
  - **Face-Aware Routing (FAR)**
    - Greedy Forwarding
      - Forwards a packet in an “as-soon-as-possible”
    - **Timed Forwarding**
      - Forwarding decision based on the “**relative times**”
Face-Aware forwarding using greedy and timed forwarding schemes
Outline

1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
   1. ACM Wireless Network, 2006
   2. IEEE ICC, Korea, 2005
4. Our HVE-mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
VE-Mobicast: A Variant-Egg-Based Mobicast Routing Protocol in Sensornets

Yuh-Shyan Chen and Shin-Yi Ann

Department of Computer Science and Information Engineering
National Chung Cheng University, Taiwan, R.O.C.

IEEE ICC 2005 (WN05-1), Seoul, Korea, 16-20, May 2005.
Mobicast framework

![Diagram of Mobicast framework with time steps t and t+1]
Motivation

- Existing protocols for a spatiotemporal variant of a multicast system were designed to support a forwarding zone that moves at a constant velocity, $v$, in sensornets.

- To consider the path of a mobile entity which includes turns, this work mainly develops a new mobicast routing protocol, called the variant-egg-based mobicast (VE-mobicast) routing protocol, by utilizing the adaptive variant-egg shape of the forwarding zone to achieve high predictive accuracy.
Delivery zone $Z[t]$, $Z[t + 1]$ and forwarding zone $F[t + 1]$ at time $t$ and $t+1$
Spatiotemporal multicast and VE-mobicast
High predictive accuracy
Application example of the VE-mobicast
System Model

- The node capabilities of all sensor nodes, including the mobile physical entities (or mobile sink node), in our work are assumed to know their location information by using GPS (Global Positioning System) or other location information-aided devices.
  - Our approach adaptively determines the forwarding zone based on the location information. Without the location information, the exact forwarding zone cannot be accurately determined.
This paper is assumed that all nodes are **synchronized**. When nodes are not synchronized, the predictive mechanism of our VE-mobicast protocol cannot be correctly performed.

- This leads to predict the incorrect size and shape of the forwarding zone, and it causes power to be needlessly consumed.

All sensor nodes are **homogeneously** and **randomly deployed** in a monitoring area by a random network. This paper is only concerned with a static and irregular topology, i.e., all sensor node locations are fixed and irregular.
Cont.

- The main operation of VE-Mobicast is depended on the control packets to determine the right forwarding zone in a distributed fashion. Therefore, this paper is not investigated the robust problem when VE-Mobicast operation losses of control packets.
Contribution

- To simultaneously consider the factors of moving speed and direction
  - This paper mainly investigates a new mobicast routing protocol, called variant-egg-based mobicast (VE-mobicast) routing protocol, by
  - To utilize the variant-egg shape of the forwarding zone to achieve mobicast forwarding with high predictive accuracy.
Our basic idea

- Our variant-egg-based mobicast routing protocol
  - A distributed and adaptive mechanism to provide a dynamic shape of variant-egg
    - Dynamically adjust the shape and size of variant-egg
    - Variant-egg-based scheme offer the result of high predicted accuracy
    - Maintaining the same number of wake-up sensor nodes in the dynamic shape of forwarding zone is the main goal of this work
Dynamic size and shape of $F_{VE}[t+1]$
A Variant-Egg-Based Mobicast Routing Protocol in Sensornets

- **Distributed and adaptive scheme** to construct an variant-egg forwarding zone
- **Two phases**
  - Phase I: Egg estimation phase
  - Phase II: Distributed variant-egg-based mobicast phase
Phase I: Egg estimation phase

\[ F_{VE}[t+1] = (x^2 + y^2)^{2} - 2e^{2}(x^2 + y^2) = 0 \]

The oval of Cassini
Phase I: Egg estimation phase

- Variant-egg forwarding zone $F_{VE}[t+1]$
  - Based on Cassini Oval

$$[(px)^2 + (qy)^2]^2 - 2e^2[(px)^2 - (qy)^2] = 0, \text{ where } \tan \theta = q/p \text{ and } p \times q = 1.$$ 

- Sensor nodes $P$ in $H[t]$ estimate the shape and size of next variant-egg $F_{VE}[t+1]$

  $$H[t] = F_{VE}[t] \cap F_{VE}[t + 1]$$
Example of phase I

\[ F_{ve}[t+1] = (x^2+y^2)^2 - 2e^2(x^2+y^2) = 0 \]

\[ L: ax + by + c = 0 \]

- \( P_1 \) forward message through \( P_2 \) within \( H = \frac{P_2P_3}{r} + 1 \)
Phase II: Distributed variant-egg-based mobicast phase

- Control packet $P_{VE}(\frac{h}{H}, N_{11}, N_{12}, \ldots, N_{1j})_{t_i}$ is used to limit the number of packet forwarding, where initial value of $H$ is the estimated hop number (from phase I) and initial value of $h$ is 0.
- If $\frac{h}{H} = 1$, stop the message forwarding.
- $N_{11}, N_{12}, \ldots, N_{1j}$ denotes the traversed-path history.
- $P_{VE}$ packet is allowed to be re-forwarded at time $t_i$.
- New $P_{VE}$ packet is forwarded at $t_x = t_y + d + \text{backoff\_time}$.
Three different regions

- Let \( \frac{h_{merge}}{H_{merge}} = \frac{\text{Min}}{\text{Max}} \frac{h_i}{H_i} \), if \( P \) is in region 1
- Let \( \frac{h_{merge}}{H_{merge}} = \frac{\text{Min}}{\text{Max}} \frac{h_i}{H_i} \), if \( P \) is in region 2
- Let \( \frac{h_{merge}}{H_{merge}} = \frac{\text{Max}}{\text{Min}} \frac{h_i}{H_i} \), if \( P \) is in region 3
Example of merging operation

(Region 1)

\[
h_{merge} = \frac{\text{Min}_{1 \leq i \leq m} h_i}{\text{Max}_{1 \leq i \leq m} H_i}
\]

(a) Region 1

(d) Region 1
Example of merging operation (Region 2)

\[
\frac{h_{\text{merge}}}{H_{\text{merge}}} = \frac{\text{Min}_{1 \leq i \leq m} h_i}{\text{Min}_{1 \leq i \leq m} H_i}
\]
Example of merging operation

(Region 3)

\[
h_{\text{merge}} \frac{h_i}{H_{\text{merge}}} = \frac{\text{Max}}{\text{Min}} \left( \frac{h_i}{H_i} \right)_{1 \leq i \leq m}
\]
Dynamic size and shape of $F_{VE}[t+1]$
Scenario of the no "hole" problem
Scenario of the "hole" problem
Performance analysis

- We provide theoretically proven bounds for the predictive accuracy and energy efficiency of our algorithm, and perform an analysis of our algorithm in terms of the number of messages used and running time.
- The simulation results are then analyzed.
Mathematical analysis

Lemma 1 The lower bound of the predictive accuracy, denoted as $R_{A_{\text{low bound}}}$, is given by

$$2 \int_{0}^{R_{d}} \frac{R_{d} - |PP'|}{\pi R_{d}^2} \sqrt{R_{d}^2 - x^2} \, dx,$$

for $0 < |PP'| = R_{d} - (|F_{t+1}Z_{t+1}| - |F_{t+1}P|) < 2R_{d}$, where $P$ is the intersection point of line $b_{1}x - a_{1}y + c_{2} = 0$ and $F_{VE}[t + 1]$. $P'$ is the intersection point of line $b_{1}x - a_{1}y + c_{2} = 0$ with $Z[t + 1]$, $R_{d}$ is the radius of the delivery zone $Z[t]$, $F_{t+1}$ is the focus of $F_{VE}[t + 1]$, and $Z_{t+1}$ is the point closest to $F_{t+1}$. 
Low Bound of Predictive Accuracy
Low Bound of Predictive Accuracy

\[ RA_{low\_bound} = \frac{\text{area of } Z[t+1] \cap \text{area of } F_{VE}[t+1]}{\text{area of } Z_{VE}[t+1]} \]

\[ = \frac{2 \int_{R_d}^{P_{PP'}} \sqrt{R_d^2 - x^2} \, dx}{\pi R_d^2} \]

\[ F_{VE}[t] = (x^2+y^2)^{1/2} - 2e (x^2+y^2) \]
Lemma 2. The low bound of energy consumption of the VE-mobicast protocol from time $t$ to $t+1$ is\[ N_{total} \times (P_t + (d-1)P_r + P_{switch}), \]where $N_{total}$ is the total number of sensor nodes in $F_{VE}[t+1]$, $d$ is the average degree of all sensor nodes, $P_t$ is the power consumption cost of one data transmission operation, $P_r$ is the power consumption cost of one data reception operation, and $P_{switch}$ is the power consumption cost of a switching operation to switch a sensor node from the sleep mode to the active mode.
Low Bound of Energy Consumption

\[ F_{\text{Area}} = \int_0^\sqrt{2e} (x^2 + y^2)^2 - 2e^2 (x^2 - y^2) \, dx \, dy \]

\[ N_{\text{total}} = \frac{F_{\text{Area}}}{R_t^2} \]

\[ = \int_0^\sqrt{2e} (x^2 + y^2)^2 - 2e^2 (x^2 - y^2) \, dx \, dy \]

The low bound of energy consumption

\[ \sum_{\alpha=1}^{N_{\text{total}}} (P_t + (d_{P\alpha} - 1)P_r + P_{\text{switch}}) \]

\[ \approx N_{\text{total}} \times (P_t + (d - 1)P_r + P_{\text{switch}}) \]

Degree of sensor node \( P_{\alpha} \)

Average degree of sensor nodes
Lemma 3. The total number of mobicast messages of the VE-mobicast protocol from time $t$ to $t + 1$ is $N_{\text{total}} \times (d - 1)$, where $N_{\text{total}}$ is the total number of sensor nodes in $F_{VE}[t + 1]$ and $d$ is the average degree of all sensor nodes.
Total Number of Mobicast Messages

\[ F_{\text{Area}} = \int_{0}^{\sqrt{2}e} (x^2 + y^2)^2 - 2e^2 (x^2 - y^2) \, dx \, dy \]

\[ N_{\text{total}} = \frac{F_{\text{Area}}}{R_t^2} \]

\[ = \frac{\int_{0}^{\sqrt{2}e} (x^2 + y^2)^2 - 2e^2 (x^2 - y^2) \, dx \, dy}{R_t^2} \]

Total Number of Mobicast Messages

Average degree of sensor nodes

\[ \sum_{\alpha=1}^{N_{\text{total}}} (d_{P_\alpha} - 1) \approx N_{\text{total}} \times (d - 1) \]

Degree of sensor node \( P_\alpha \)

Transmission range
Lemma 4. The running time of the VE-mobicast protocol from time $t$ to $t+1$ is $(\frac{\sqrt{2e}}{R_t} - 1) \times ((d - 1)T_r + T_b)$, where $\frac{\sqrt{2e}}{R_t}$ is the diameter of the $F_{VE}[t+1]$, $d$ is the average degree of all sensor nodes, $T_r$ is the time cost of data transmission, and $T_b$ is the random backoff time.
The Running Time

Total running time = \sum_{\alpha=1}^{\frac{\sqrt{2e}}{R_t} - 1} (d_{P_{\alpha}} - 1) T_r + T_b

Random backoff time

\approx \left( \frac{\sqrt{2e}}{R_t} - 1 \right) \times ((d - 1) T_r + T_b)
Simulation result

- Our paper presents a variant-egg-based mobicast protocol. To evaluate our VE-mobicast protocol (VE-mobicast), Huang et al.’s mobicast protocol (mobicast) [10], and the FAR protocol (FAR) [12],
  - all these protocols are mainly implemented using the NCTUns 2.0 simulator and emulator [28].

- The simulation environment
  - 1000 x 800 m² area with 800 sensor nodes which are setting by random
  - The communication radius of sensor node is 35 meters
  - The delivery zone is a circular delivery zone
    - velocity is 45 m/sec and radius is 45 meters
  - Consumption of power is denoted as $n = W$ (watt)
    - $n = 1$, sensor node in sleeping mode
    - $n = 5$, sensor node in active mode
    - $n = 10$, sensor node transmits the message
The initial estimated shape of the variable-egg

- The predictive accuracy gap is defined as \( GPA(p,q) = PA_{optimal} - PA_{p,q} \), where \( PA_{p,q} \) denotes the predictive accuracy (PA) under given values of \( p \) and \( q \), where \( p \times q = 1 \).

\[
[(px)^2 + (qy)^2] - 2e^2[(px)^2 - (qy)^2] = 0, \text{ where } \tan \theta = q/p \text{ and } p \times q = 1.
\]
Performance of the average predictive accuracy gap $GPA(p,q)$ vs. (a) the rotation angle ($10\% \leq RF \leq 100\%$), (b) the rotation frequency ($6 \leq ND \leq 20$ nodes/m$^2$)
Performance of the average predictive accuracy gap $GPA(p,q)$ vs. (c) the network density ($10\% \leq RF \leq 100\%$).
Performance Metrics

- The **predictive accuracy (PA)** is the percentage of sensor nodes located in both $Z[t+1]$ and $F_{VE}[t+1]$ (or $F[t+1]$) divided by the total number of sensor nodes in $Z[t+1]$, i.e., $PA = 100\%$ if all nodes in $Z[t+1]$ are located in $F_{VE}[t+1]$ (or $F[t+1]$).

- The **packet overhead ratio (POR)** is the total number of packets that all sensor nodes transmit, including the control and mobicast messages, divided by the minimum number of packets used in our VE-mobicast protocol.
Cont.

- The *throughput* (TP) is the total number of data packets the mobile entity receives from sensor nodes in $Z[t+1]$ per second.

- The *power consumption ratio* (PCR) is the total power consumption of all sensor nodes divided by the minimum power consumption of our VE-mobicast protocol.
Simulation result

The **predictive accuracy (PA)** is the percentage of sensor nodes located in both $Z[t+1]$ and $F_{VE}[t+1]$ (or $F[t+1]$) divided by the total number of sensor nodes in $Z[t+1]$, i.e., $PA = 100\%$ if all nodes in $Z[t+1]$ are located in $F_{VE}[t+1]$ (or $F[t+1]$).
Performance of the predictive accuracy vs. the rotation angle, where (a) the rotation frequency = 10%, (b) the rotation frequency = 50.
Performance of the predictive accuracy vs. the rotation angle, where (c) the rotation frequency = 100%, and (d) 10% ≤ the rotation frequency ≤ 100%.
Performance of the predictive accuracy vs. the rotation frequency, where (a) the network density = 6 nodes/m², (b) the network density = 12 nodes/m².
Performance of the predictive accuracy vs. the rotation frequency, where (c) the network density $= 20 \text{ nodes/m}^2$, and (d) $6 \text{ nodes/m}^2 \leq \text{the network density} \leq 20 \text{ nodes/m}^2$. 
Performance of the predictive accuracy vs. the network density, when (a) the rotation angle $= 5^\circ$, (b) the rotation angle $= 30^\circ$. 

![Graph (a)](image1)

![Graph (b)](image2)
Performance of the predictive accuracy vs. the network density, when (c) the rotation angle = $50^\circ$, and (d) $5^\circ \leq$ the rotation angle $\leq 50^\circ$. 

(c) 

(d)
Simulation result

- The *packet overhead ratio (POR)* is the total number of packets that all sensor nodes transmit, including the control and mobicast messages, divided by the minimum number of packets used in our VE-mobicast protocol.
Performance of average packet overhead ratio (POR) vs. (a) rotation angle (RA), (b) rotation frequency (RF), and (c) network density (ND)
Simulation result

- The **throughput** (TP) is the total number of data packets the mobile entity receives from sensor nodes in $Z[t+1]$ per second.
Performance of the average throughput (TP) vs. (a) rotation angle (RA), (b) rotation frequency (RF), and (c) network density (ND)
Simulation result

- The *power consumption ratio (PCR)* is the total power consumption of all sensor nodes divided by the minimum power consumption of our VE-mobicast protocol.
Performance of the average power consumption ratio (PCR) vs. (a) rotation angle (RA), (b) rotation frequency (RF), and (c) network density (ND)
Conclusion

- In this paper, we present a new "spatiotemporal multicast" protocol for supporting applications which require spatiotemporal coordination in a sensornet.

- To consider the path of a mobile entity which includes turns, in this paper, we develop a new mobicast routing protocol, called the variant egg-based mobicast (VE-mobicast) routing protocol, by utilizing an adaptive variant-egg shape for the forwarding zone to achieve high predictive accuracy.
Outline

1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
   1. ACM Wireless Network, 2006
   2. IEEE ICC, Korea, 2005
4. Our HVE-mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
Extended result

HVE-mobicast routing protocol

\[ F_{\text{req}}[t] \quad F_{\text{req}}[t+1] \]

\[ F_{\text{req}}[t] \quad F_{\text{req}}[t+1] \]

VE-mobicast

\[ t_1 \quad \ldots \quad t_{30} \]

- Wake up
- Wait
- Wake up members

(a)

(b)
Outline

1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
   1. ACM Wireless Network, 2006
   2. IEEE ICC, Korea, 2005
4. Our HVE-mobicast routing protocol
   1. IEEE WCNC, USA, 2006
5. Conclusion
Conclusion

- This work develops a new mobicast routing protocol for WSN (wireless sensor network).

- Future work
  - multi-sinks mobicast routing protocol.
Homework #12:

1. What’s mobicast routing protocol in WSNs?