Chapter 11 :Mobicast Routing Protocol in Wireless Sensor Networks

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

Publications

- **IEEE ICC, Korea, 2005**
- **ACM/Springer Wireless Network (MINET), April 2008**

Outline

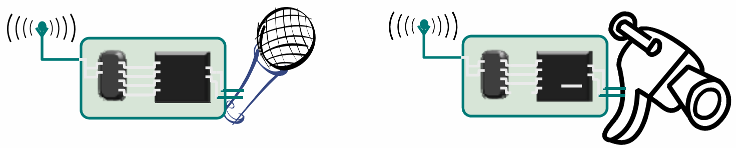
1. Introduction
2. Related works
3. Our VE-mobicast routing protocol
4. Conclusion

Introduction

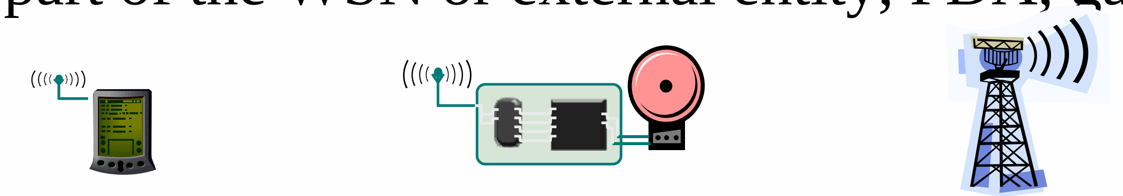
- Participants in the MANET (mobile ad hoc network) were devices close to a human user, interacting with **humans**
- Alternative concept of WSN (wireless sensor network): Instead of focusing interaction on humans, focus on interacting with **environment**
  - Network is ***embedded*** in environment
  - Nodes in the network are equipped with ***sensing*** and ***actuation*** to measure/influence environment
  - Nodes process information and communicate it wirelessly

Roles of participants in WSN

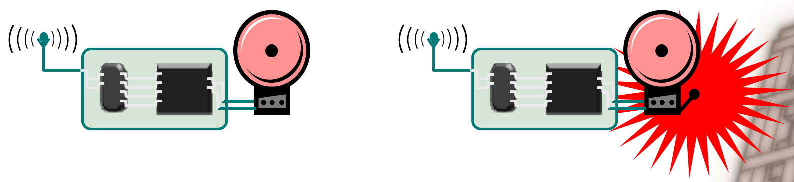
- ***Sources*** of data: Measure data, report them "somewhere"
  - Typically equip with different kinds of actual sensors



- ***Sinks*** of data: Interested in receiving data from WSN
  - May be part of the WSN or external entity, PDA, gateway, …

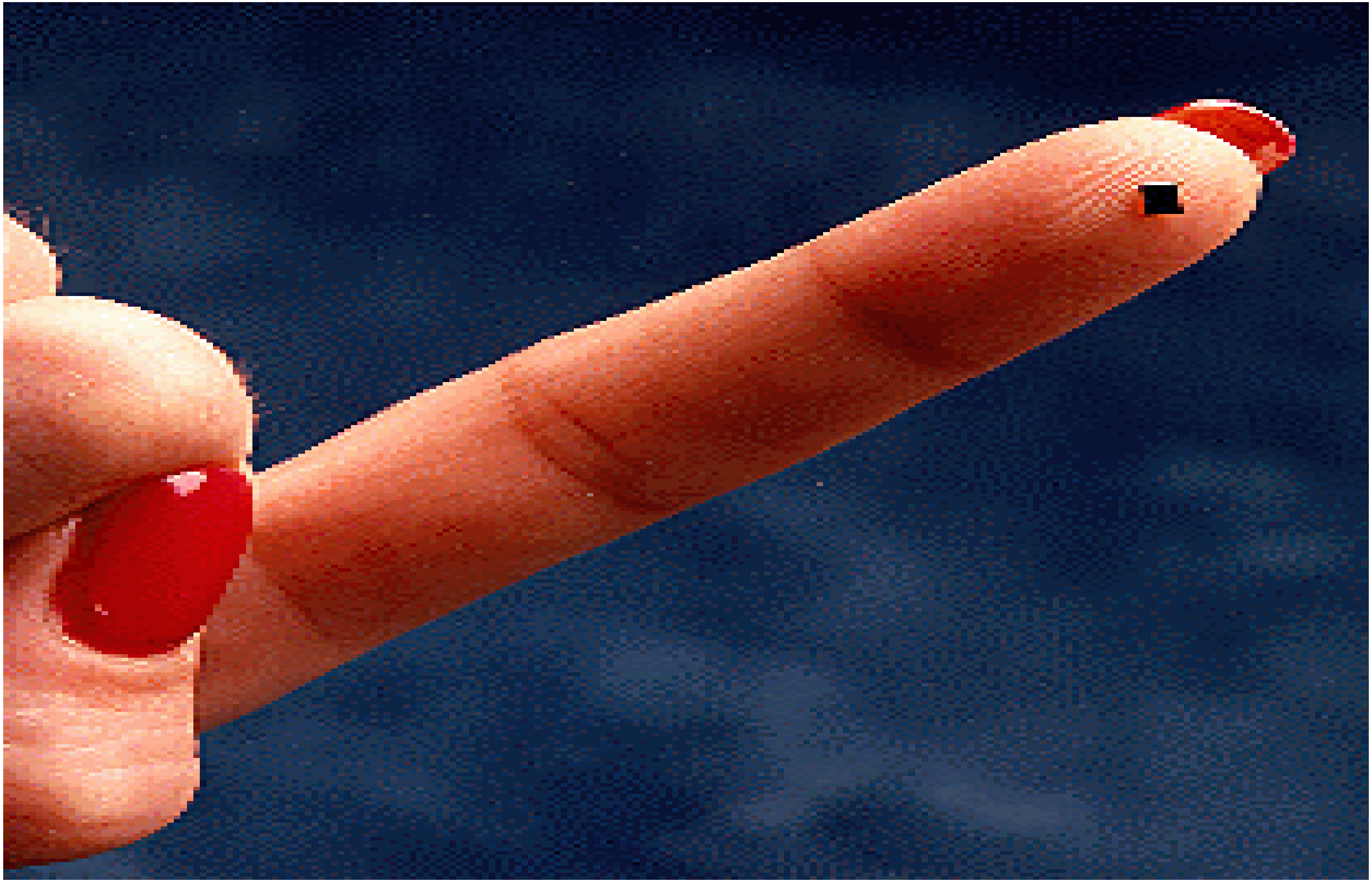


- ***Actuators***: Control some device based on data, usually also a sink



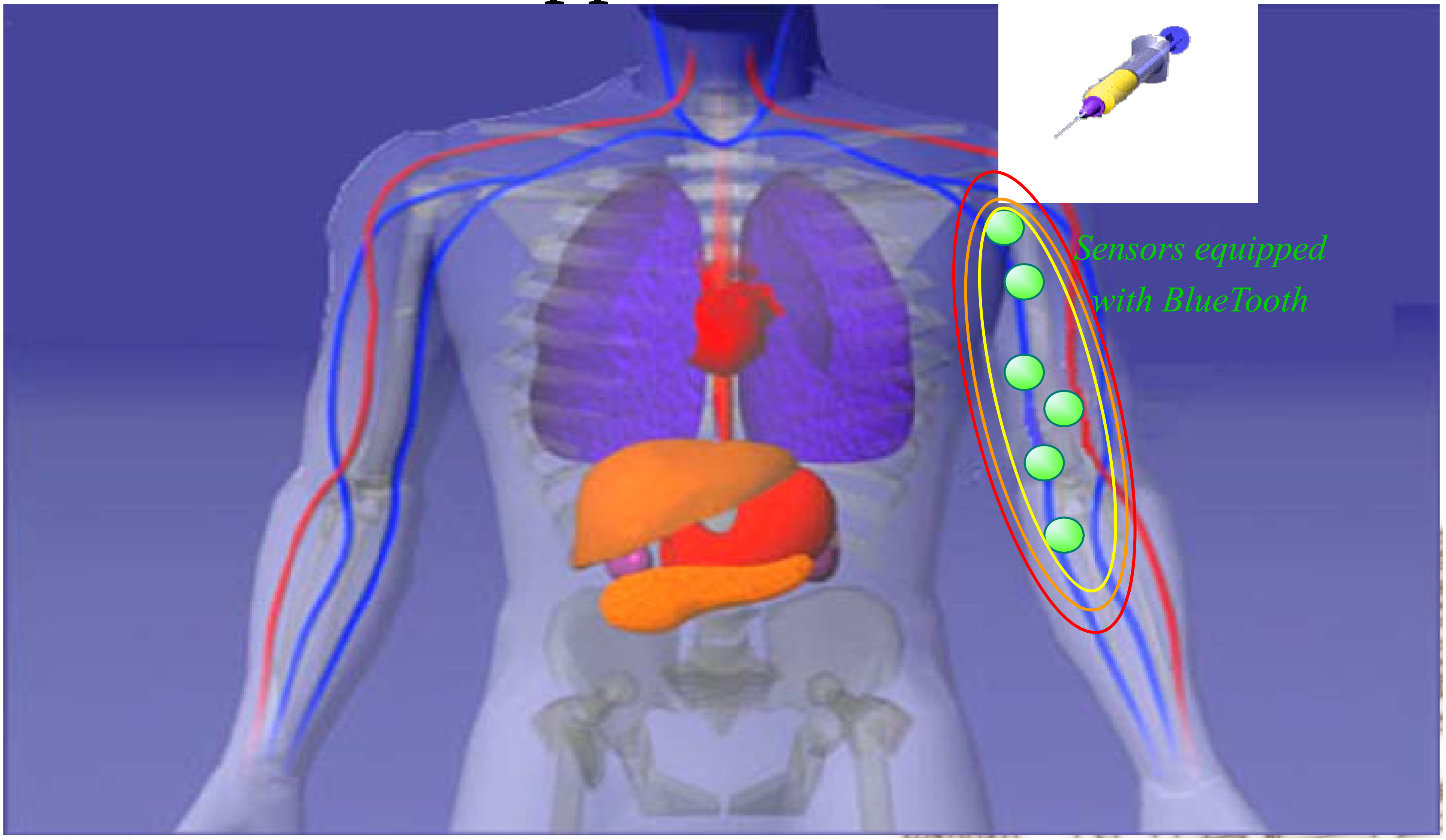
MICA*z* - 2.4 GHz IEEE 802.15.4/ZigBee™ Compliant Mote

Example of Wireless Bio-Sensor

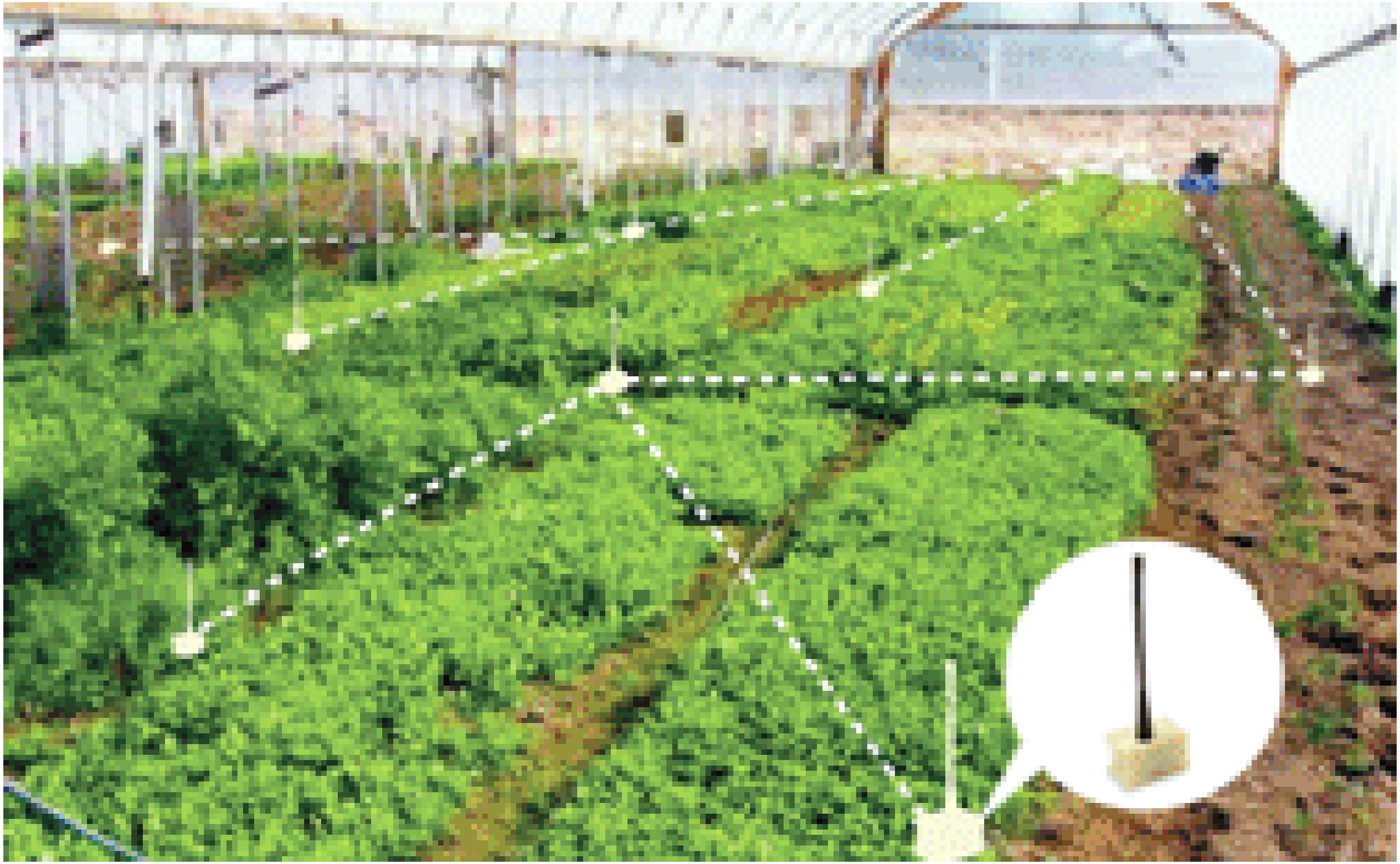


Medical and **Healthcare** Applications

Source: USC Web Site



Environment Monitoring System

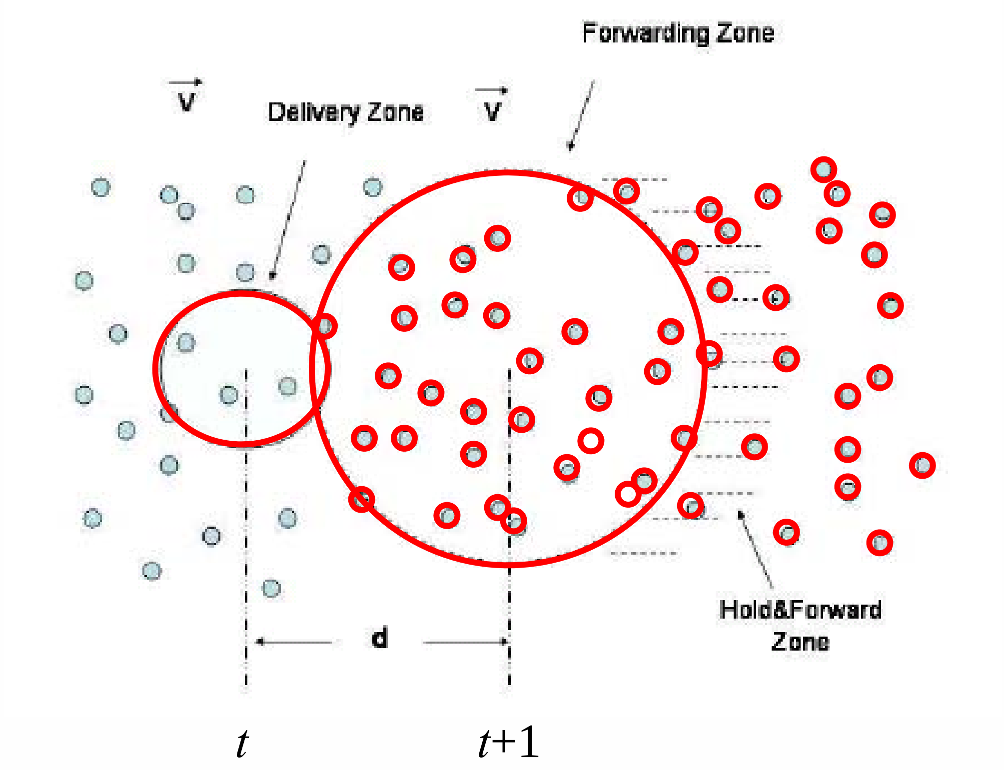


Sensors in Unknown Terrain

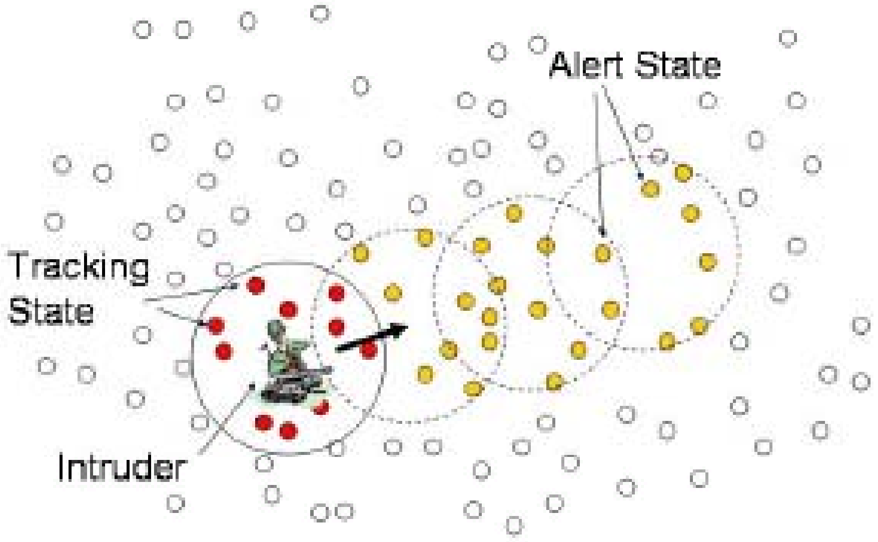
Mobicast

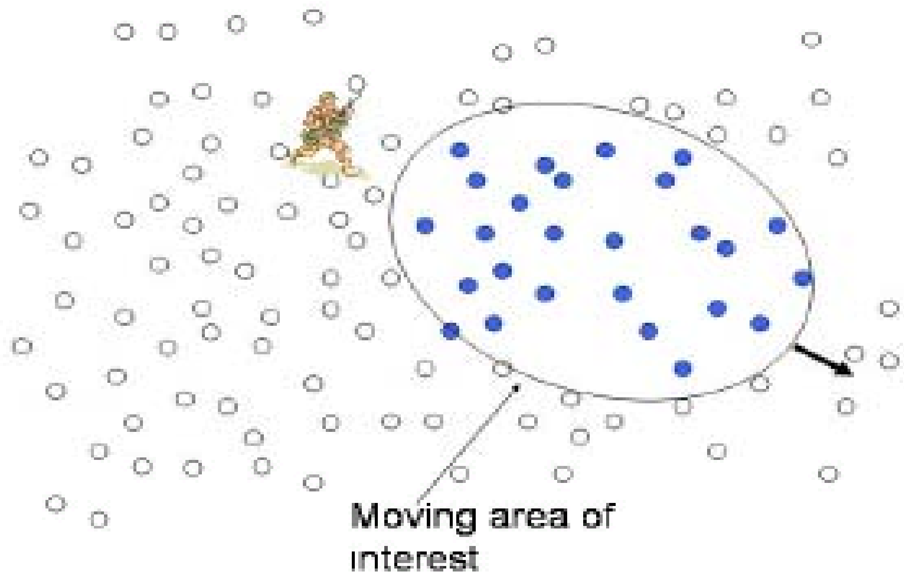
- In this talk, we consider a new "**mobicast**" routing protocol in the wireless sensornets
  - A spatiotemporal variant of **multicast** called a "mobicast" were designed to support a **forwarding zone** that moves at a constant velocity, v , in sensornets.
  - This spatiotemporal multicast protocol provides sensing applications that need to transfer the multicast message to the "right" **place** at the "right" **time**.

Mobicast framework

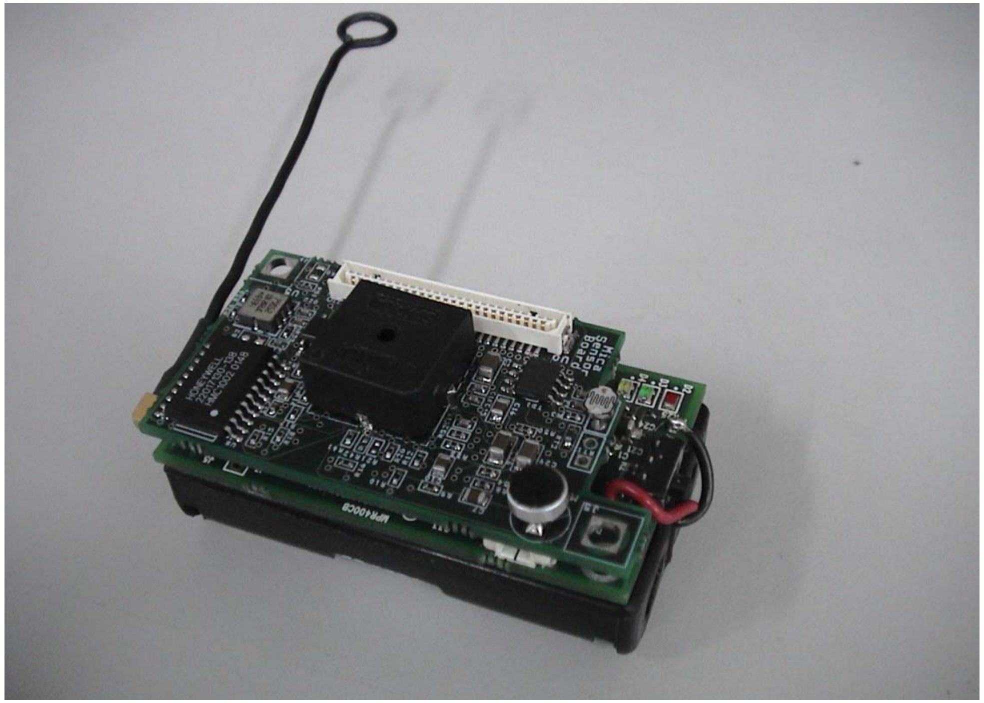


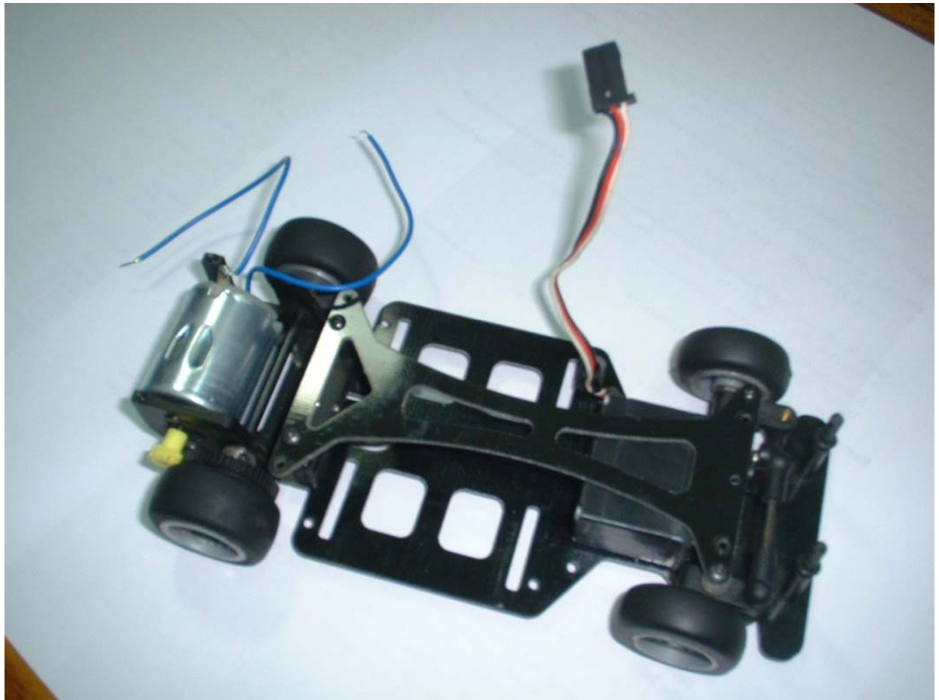
Mobicast applications





Our Mobile-Sink Implementation



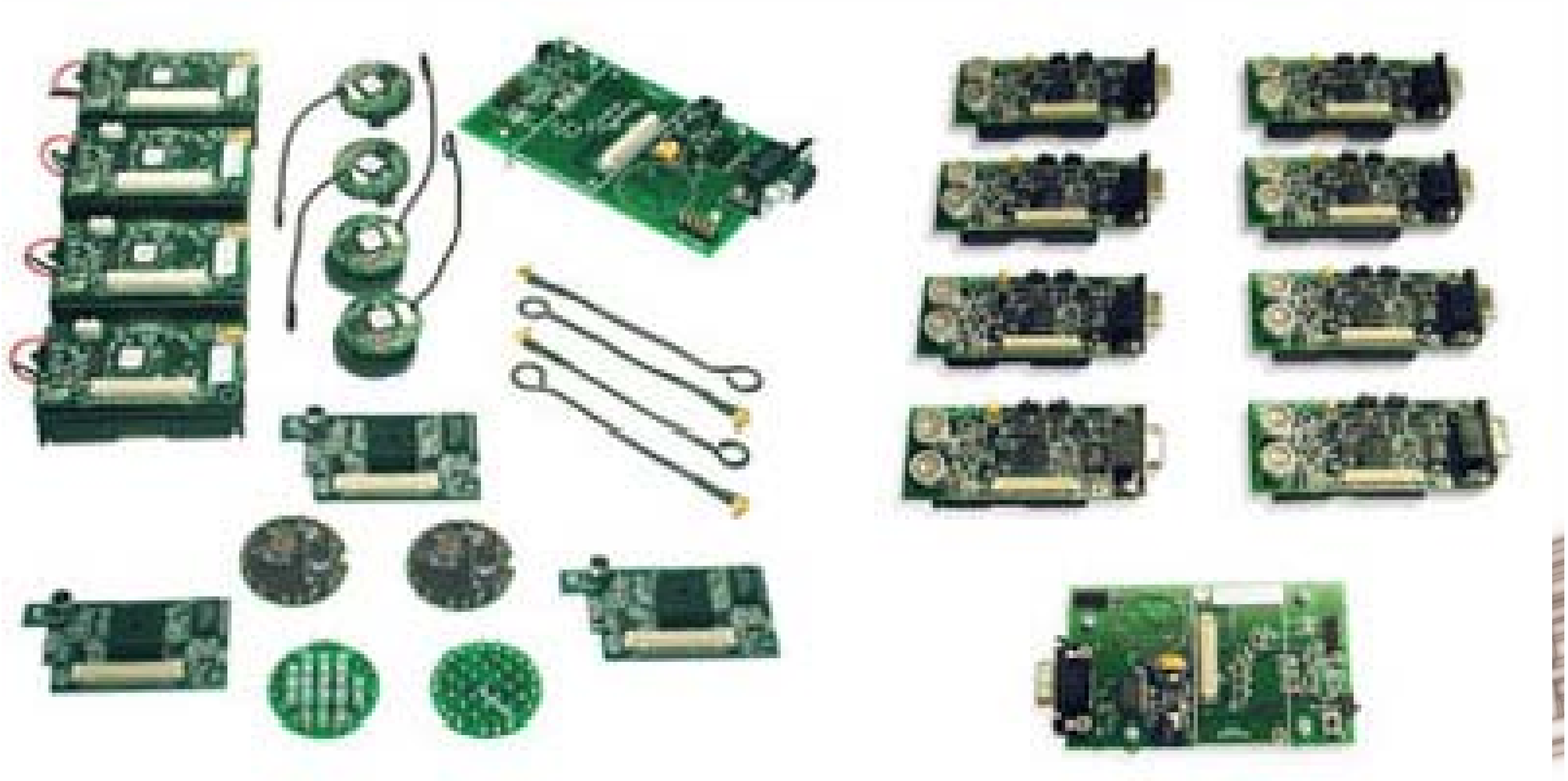


Motes

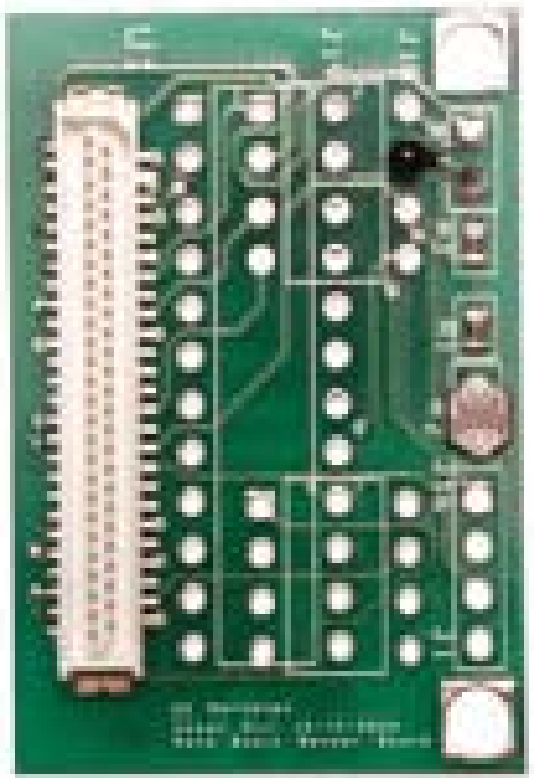
Smart Dust Sensors, Wireless Sensor Networks

(http://www.xbow.com/)

Mote Kits



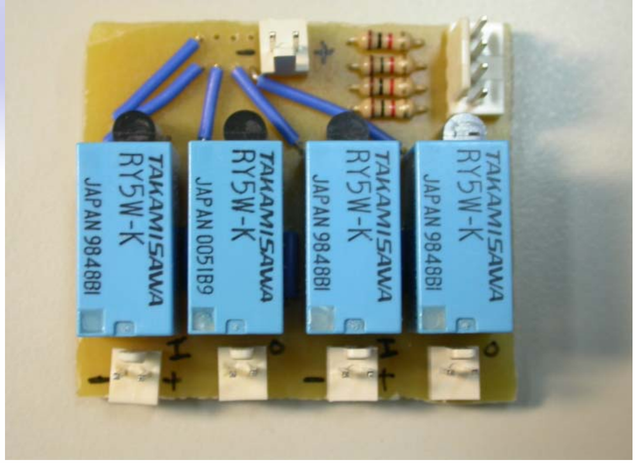
MTS101 – Basic Sensor Module

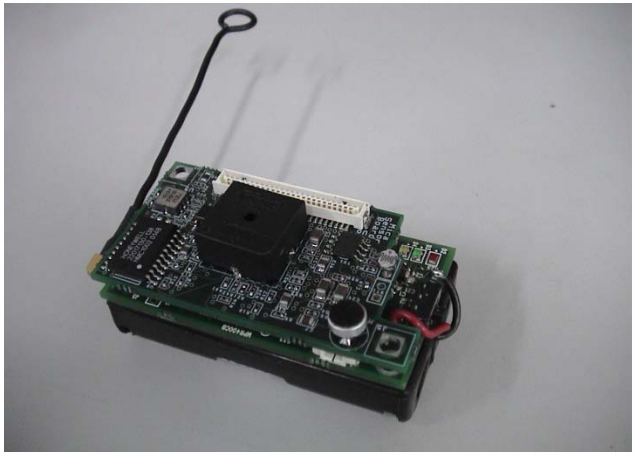


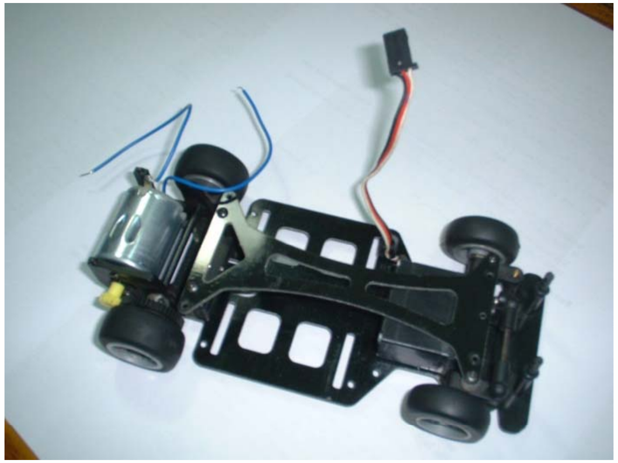
MICA2DOT Multi-Sensor Module (MTS510)

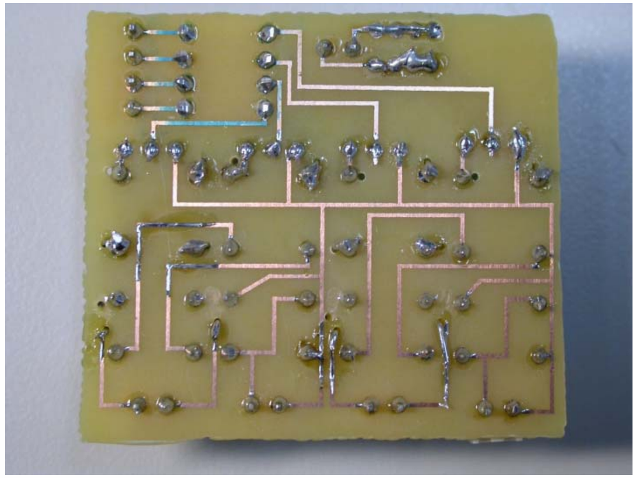
MICA*z* - 2.4 GHz IEEE 804.15.4/ZigBee™ Compliant Mote

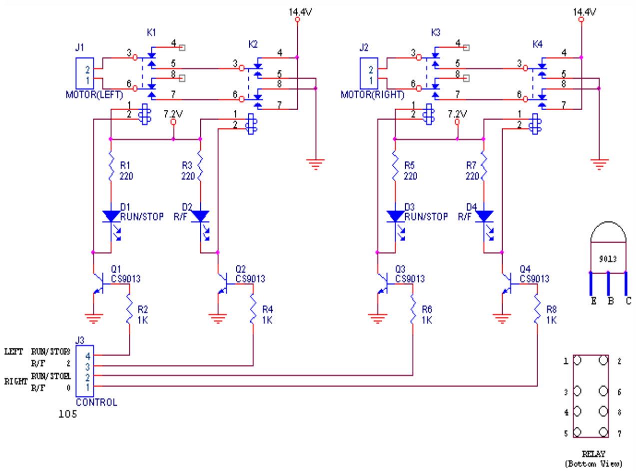
Our Implementation

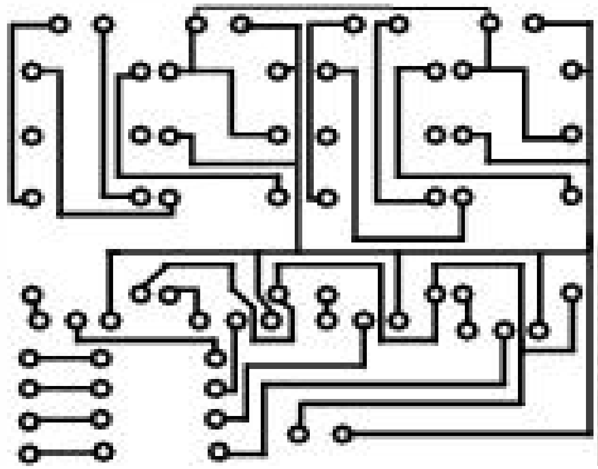


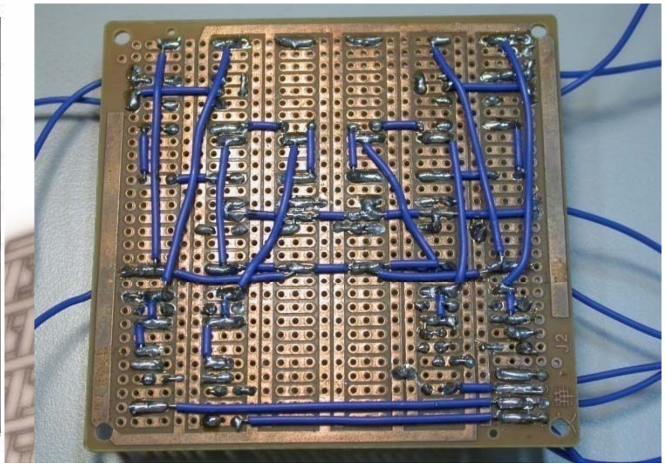




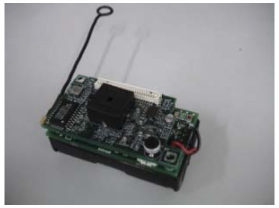




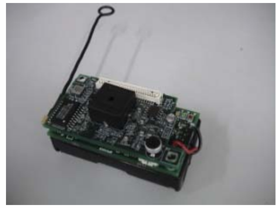
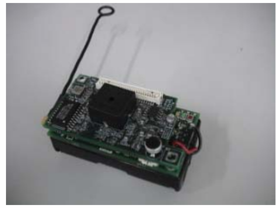
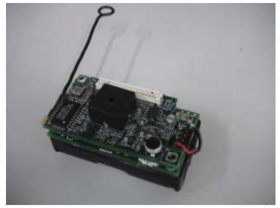




多媒體無線行動感測車







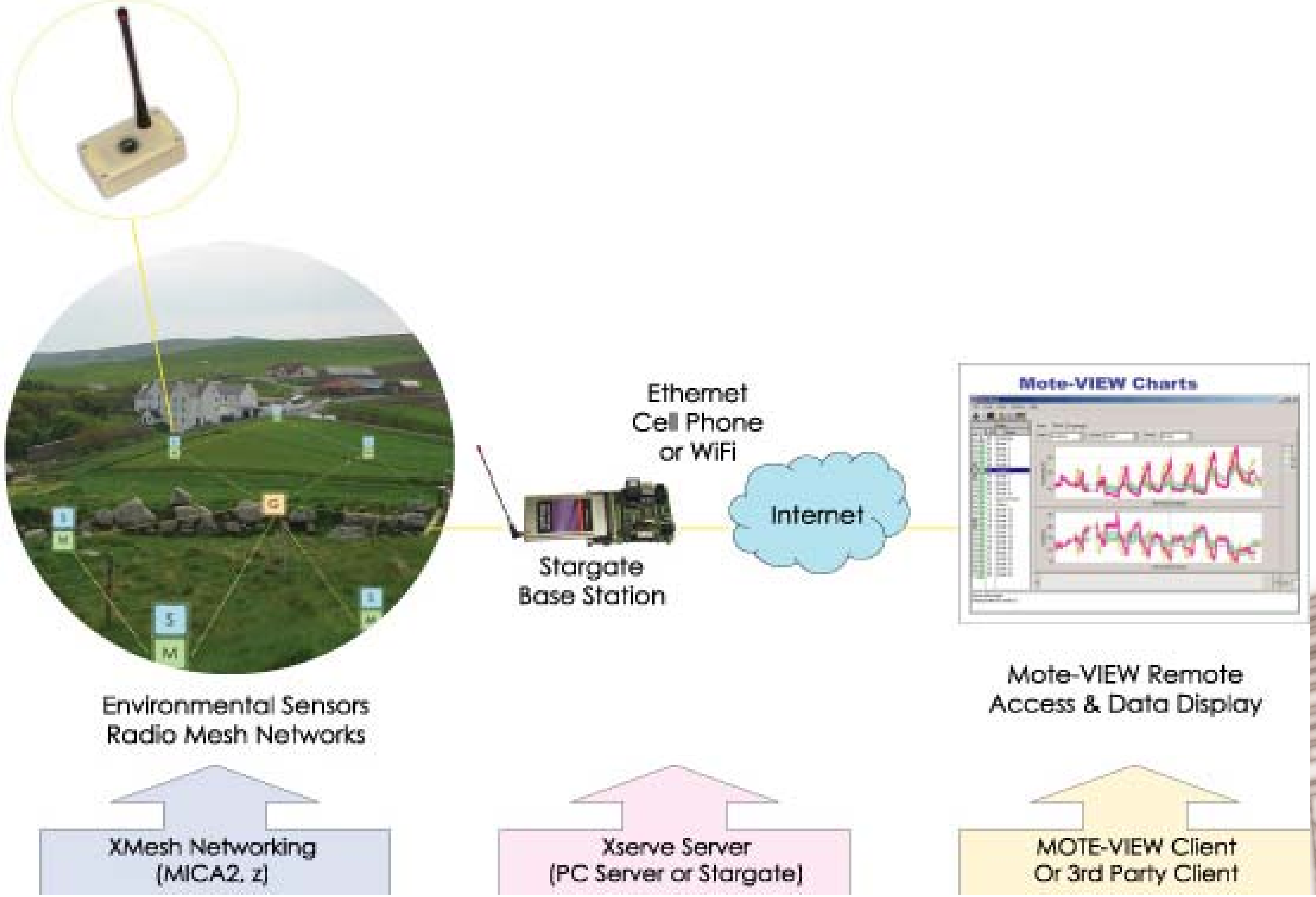
Shelving Filter

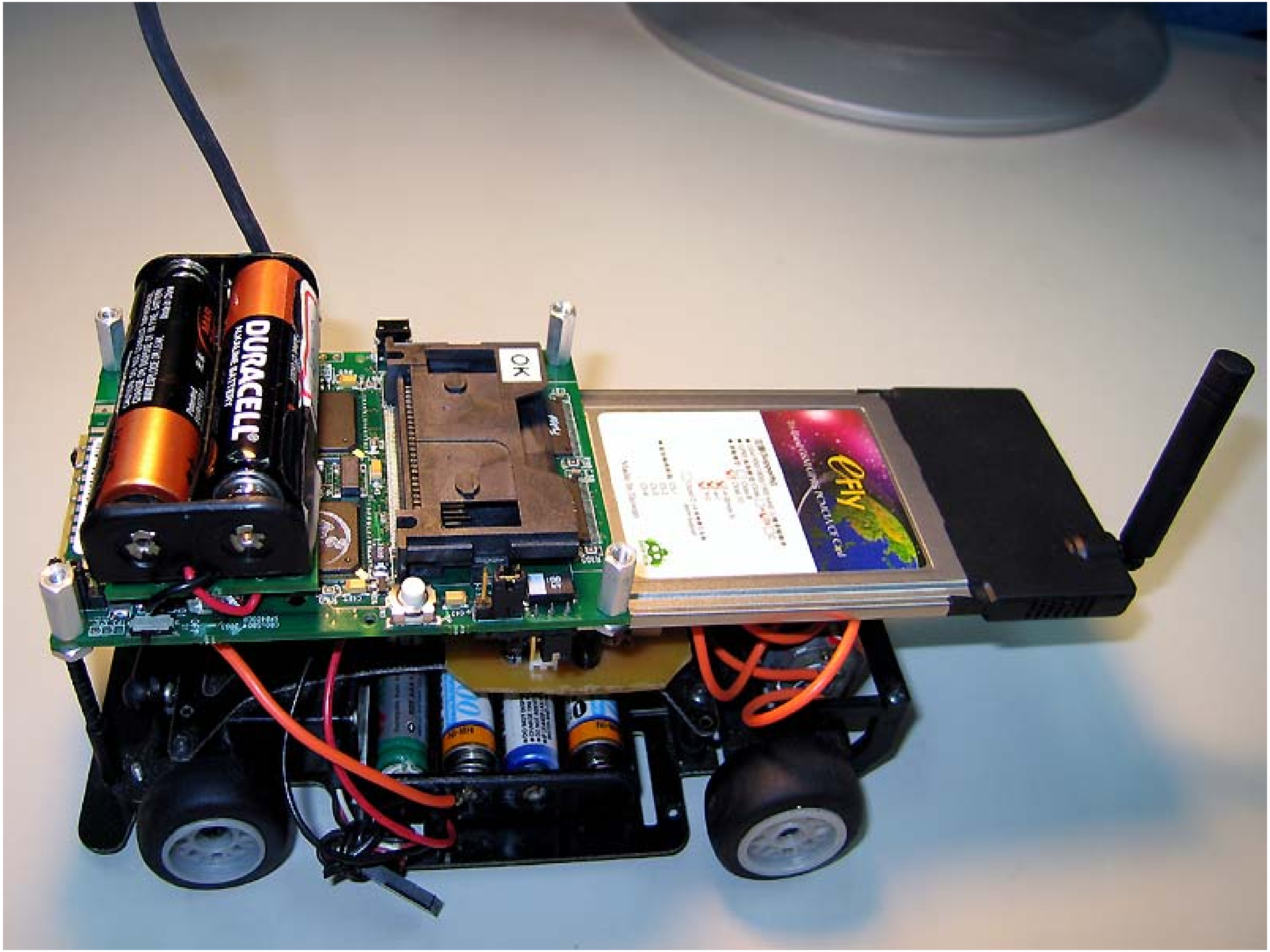
MEP410CA– Micro Climate Multi-Sensor Node

Gateway & Network Interface Modules

- **Stargate** - XScale Network Interface and Single Board Computer

http://www.xbow.com/Products/productsdetails.aspx?sid=3

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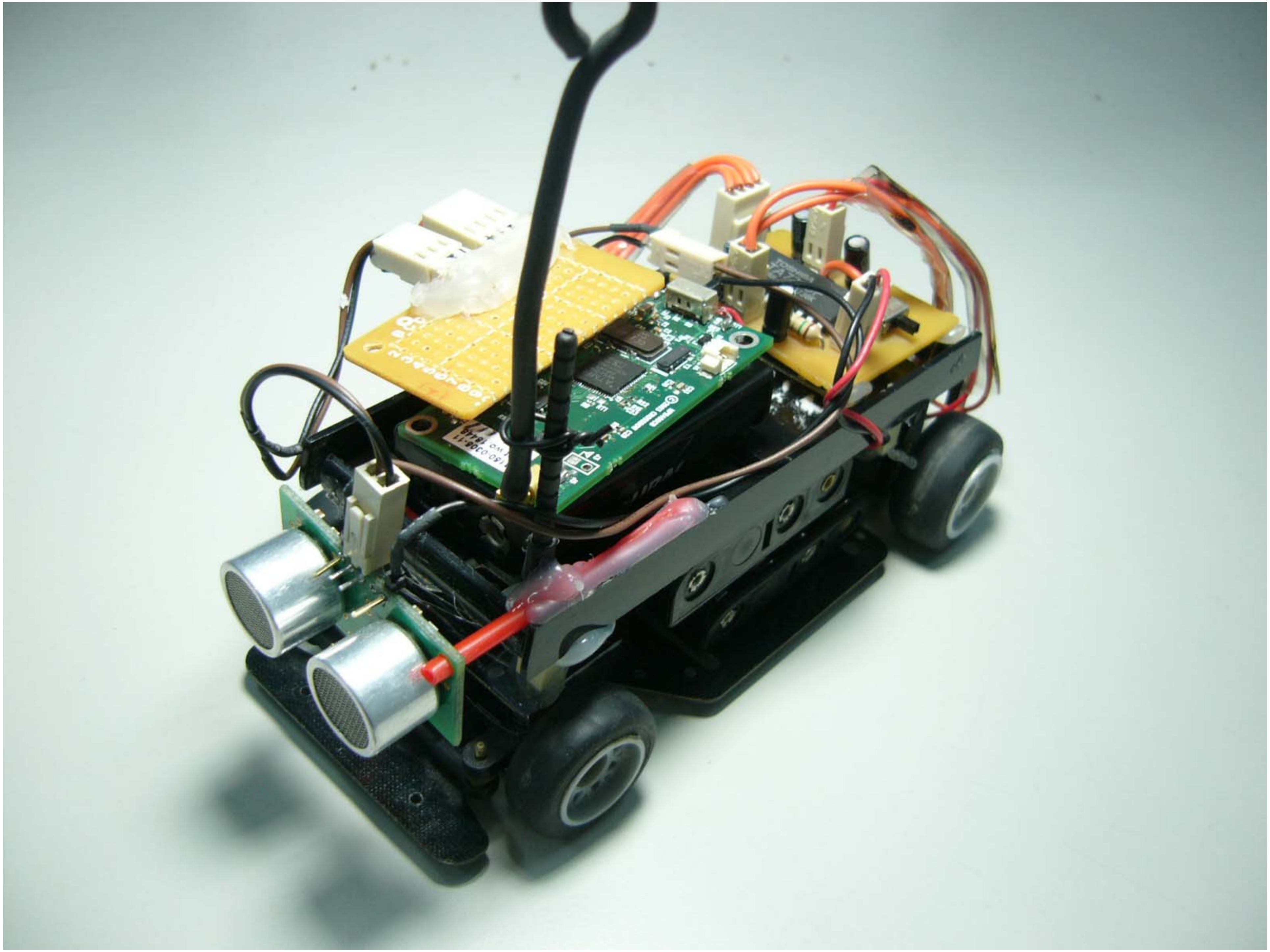
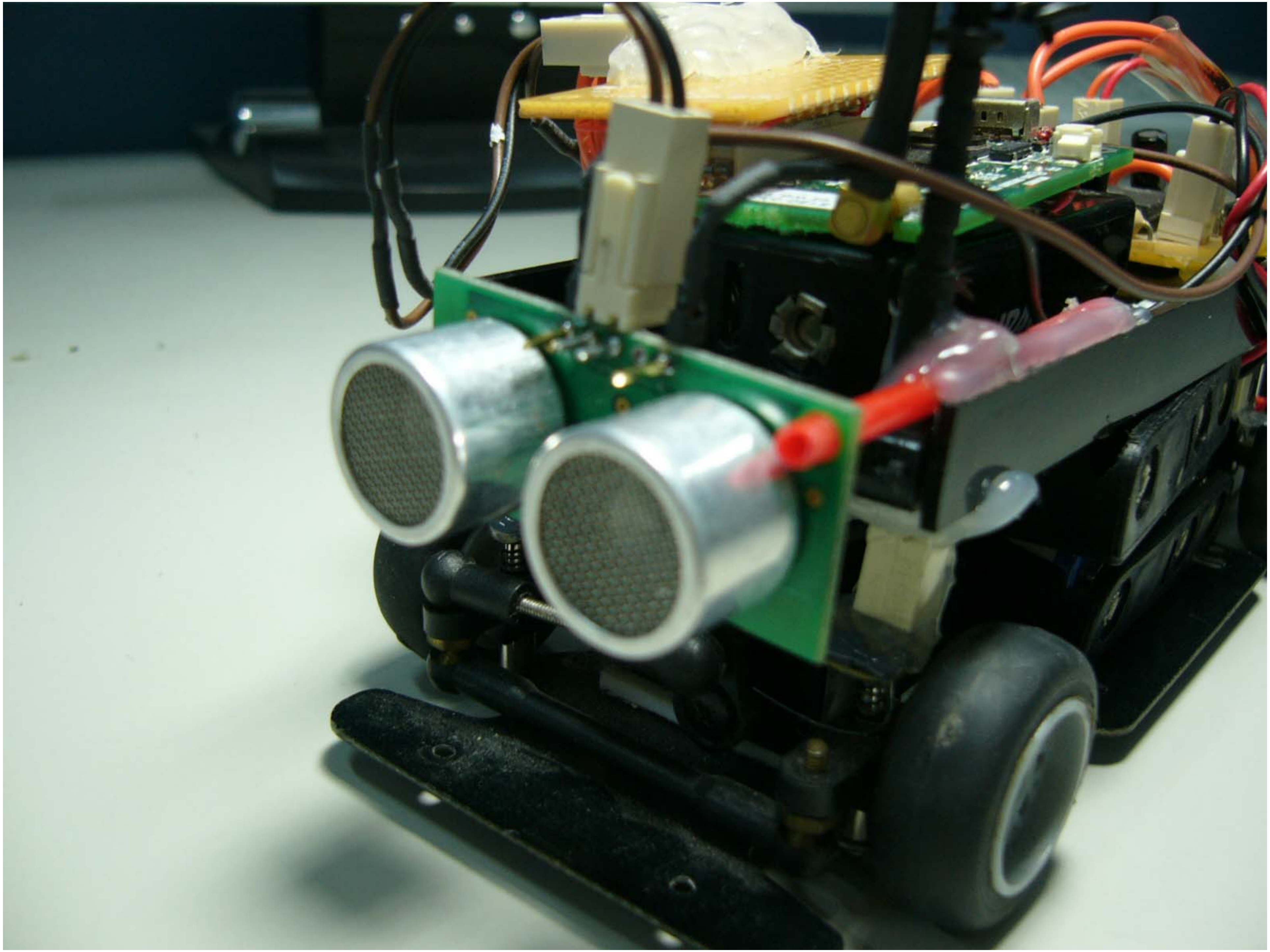
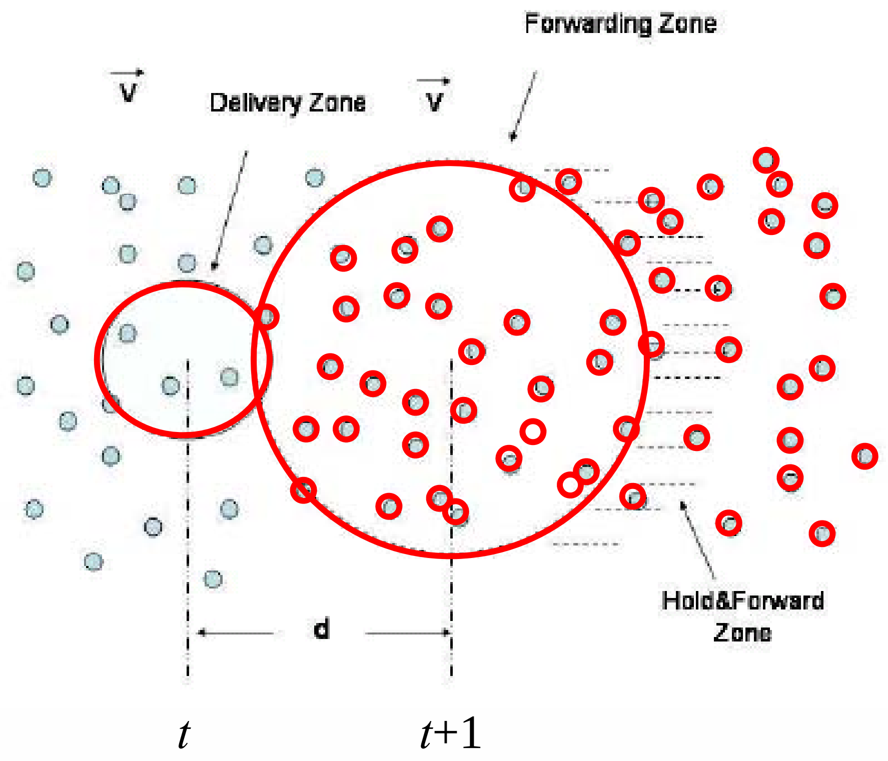
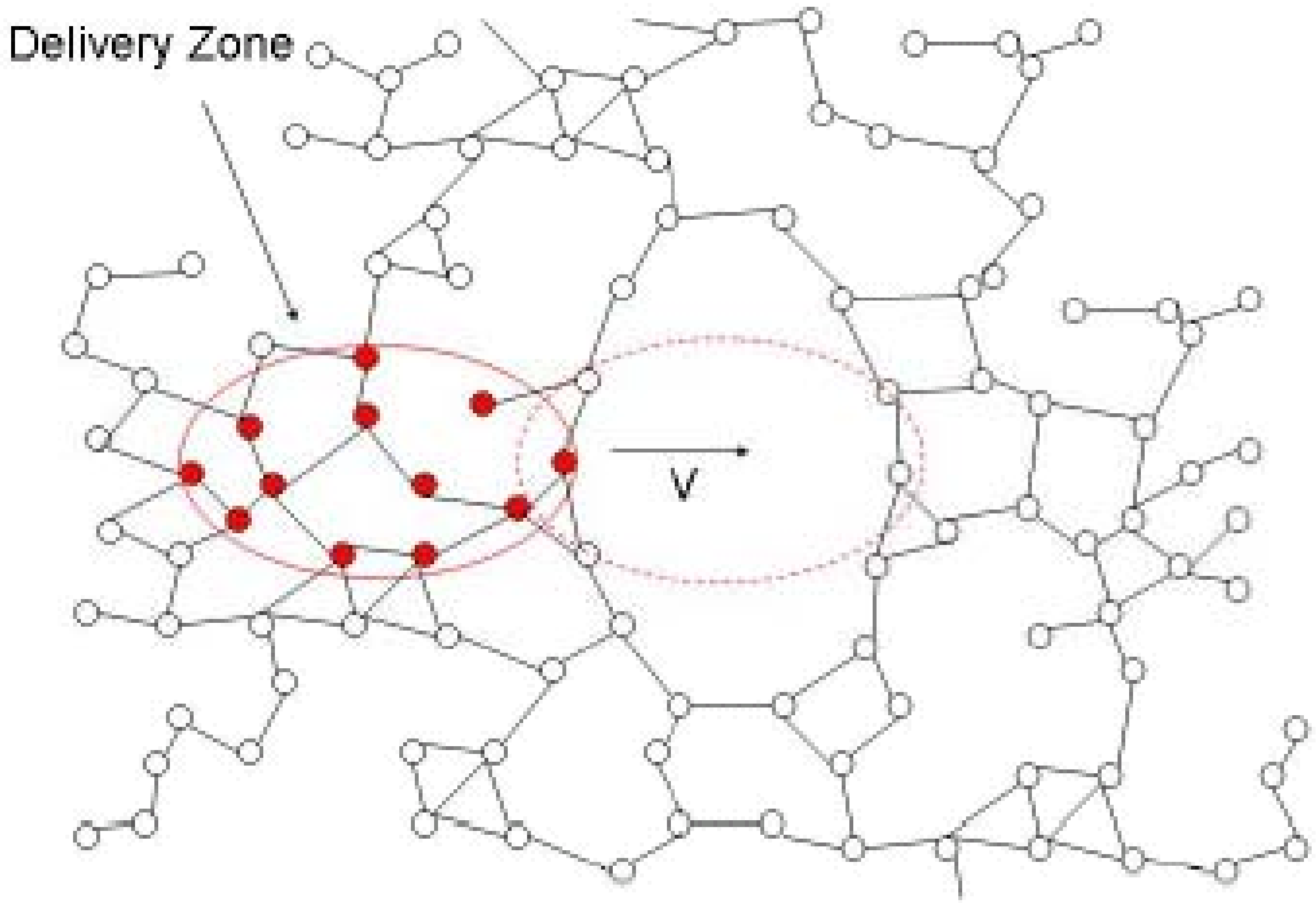




Mobicast framework



Key problem: “**hole**” problem



Outline

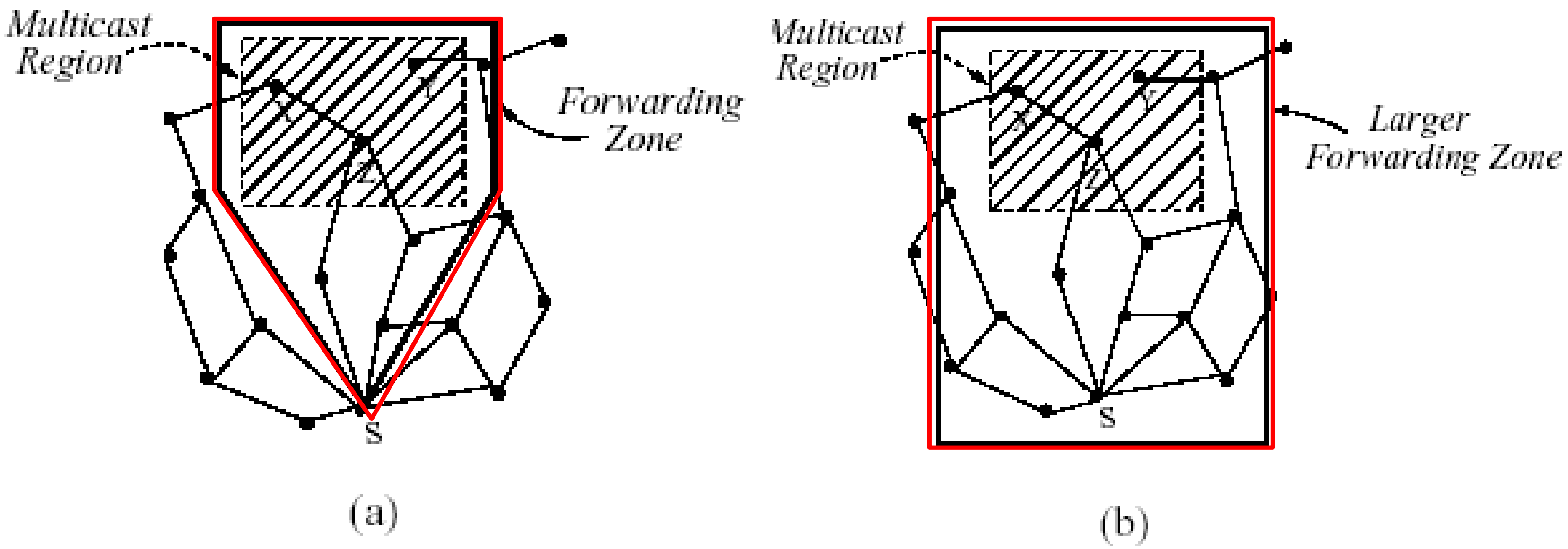
1. Introduction
2. Related works
3. Our mobicast routing protocol
    1. **ACM Wireless Network (accepted)**
    2. **IEEE ICC, Korea, 2005**
4. Our enhanced mobicast routing protocol
    1. **IEEE WCNC, USA, 2006**
5. Conclusion

Related Works

- **Multicast**
  - **IEEE INFOCOM (2000), MSWiM (2000), WCNC (2003), IEEE GLOBECOM (2003).**
- **Geocasting**
  - Ko *et al.*, *"*Geocasting in Mobile Ad Hoc Networks: Location-Based Multicast Algorithms",**WMCSA (IEEE Workshop on Mobile Computing System & Applications)**, 1999.
- **Mobicasting**
  - Huang *et al.*, *"*Design and Analysis of Spatiotemporal Multicast Protocols", **Telecommunication System**, Aug. 2004.
  - Huang *et al.*, *"*Spatiotemporal Multicast in Sensor Networks," **ACM SenSys**, Nov, 2003.
  - Huang *et al.*, *"*Reliable Mobicast via Face Aware Routing", **IEEE INFOCOM**, March 2004.

Ko *et al.*, "Geocasting in Mobile Ad Hoc Networks: Location-Based Multicast Algorithms",WMCSA, Feb. 1999.

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

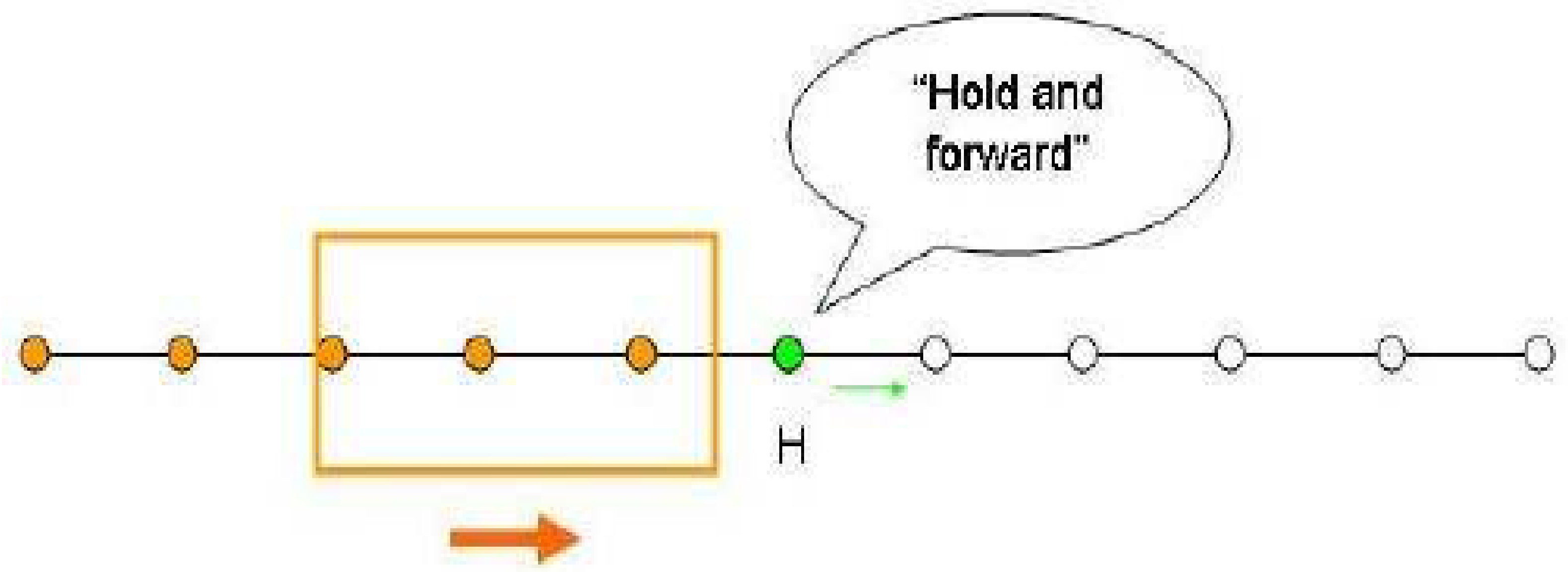


Huang *et al.*, "Design and Analysis of Spatiotemporal Multicast Protocols", **Telecommunication System (SCIE)**, Aug. 2004.

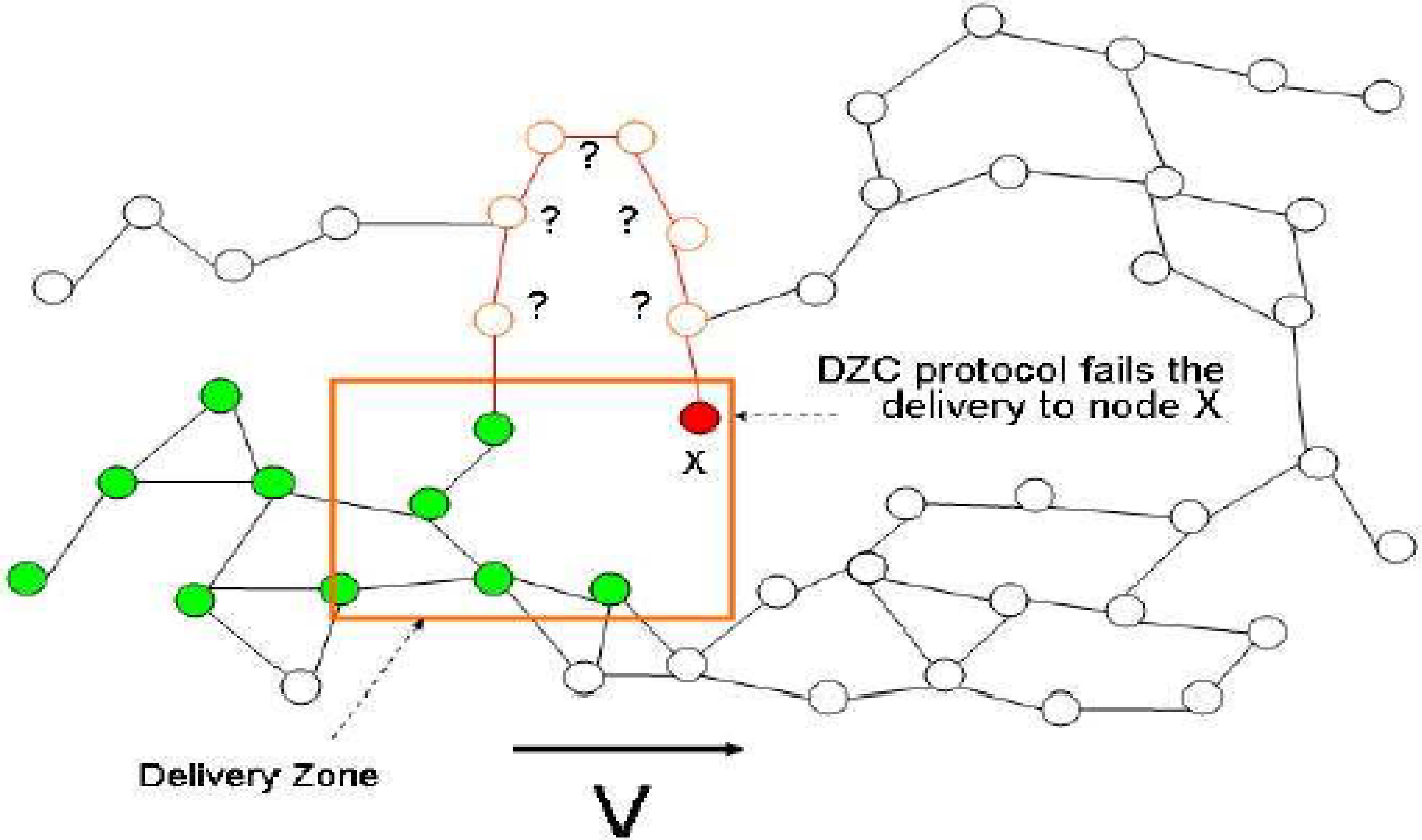
- A Spatiotemporal multicast protocols for sensornets
  - A new multicast routing protocol
    - Multicast message be disseminated to the "right-place" at the "right-time"
  - A special class of spatiotemporal multicast
    - Mobicast routing protocol
      - A delivery zone that translates through a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

Simple Mobicast Sloutions

- Hold-and-Forward
  - Only nodes on the path of the delivery zone will participate.
  - Delivery-Zone-constrained (DZC) protocol



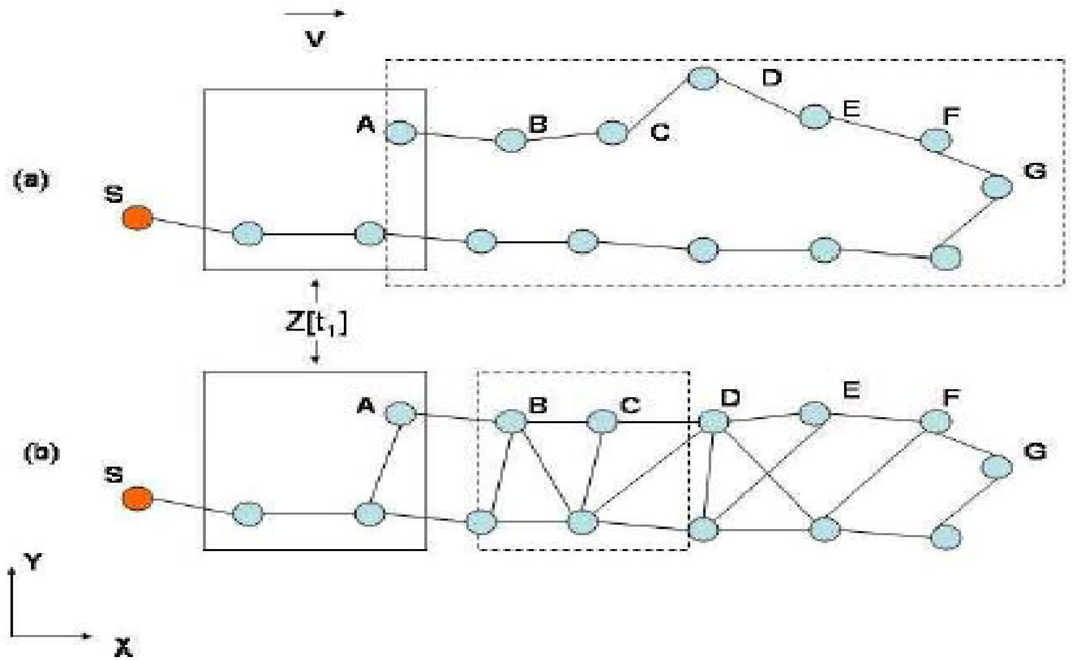
DZC Protocol Cannot Guarantee Delivery



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

A Reliable Mobicat Protocl

- 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

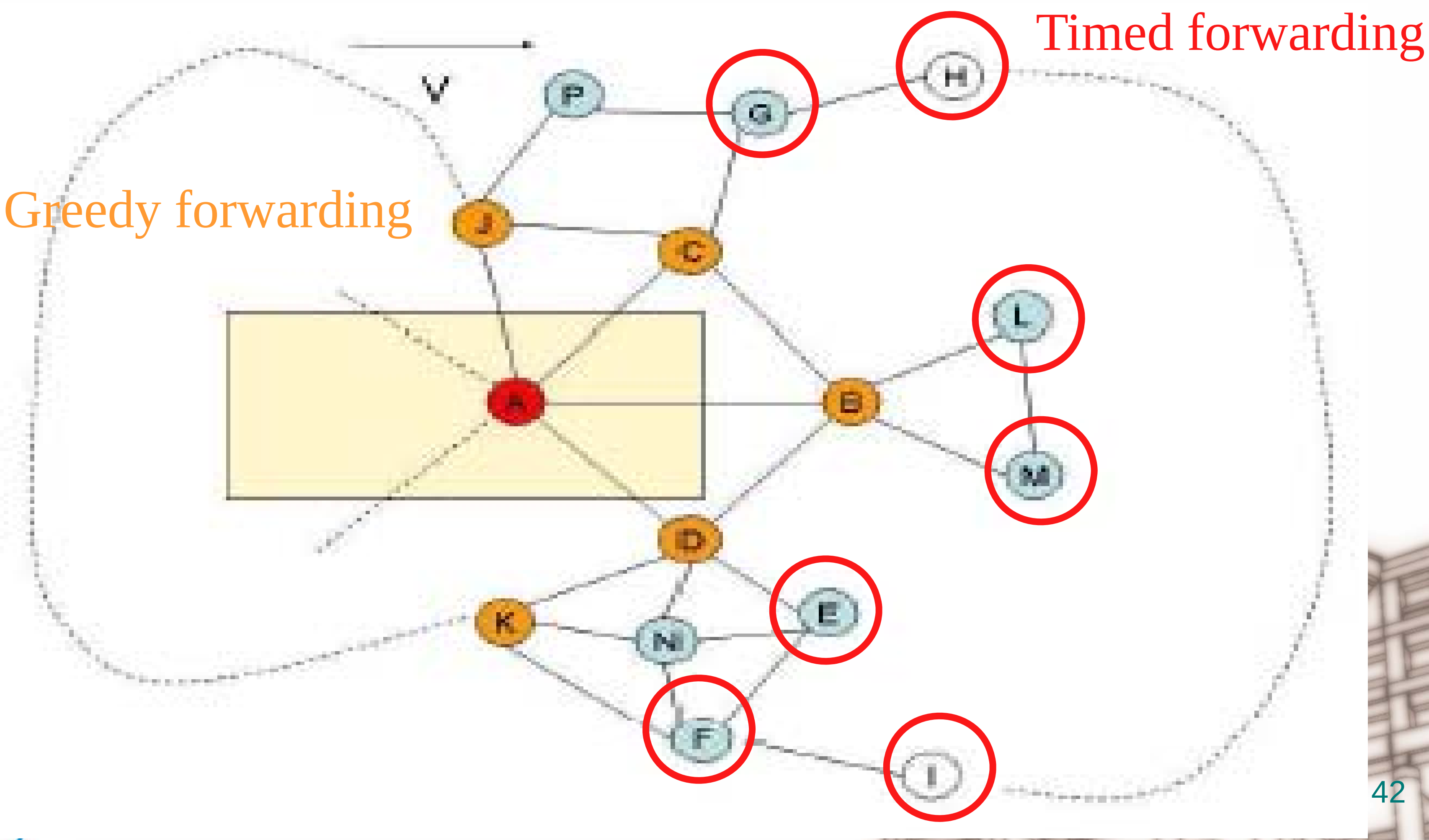
Huang *et al.*, "Spatiotemporal Multicast in Sensor Networks," **ACM SenSys**, Nov, 2003.

- 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

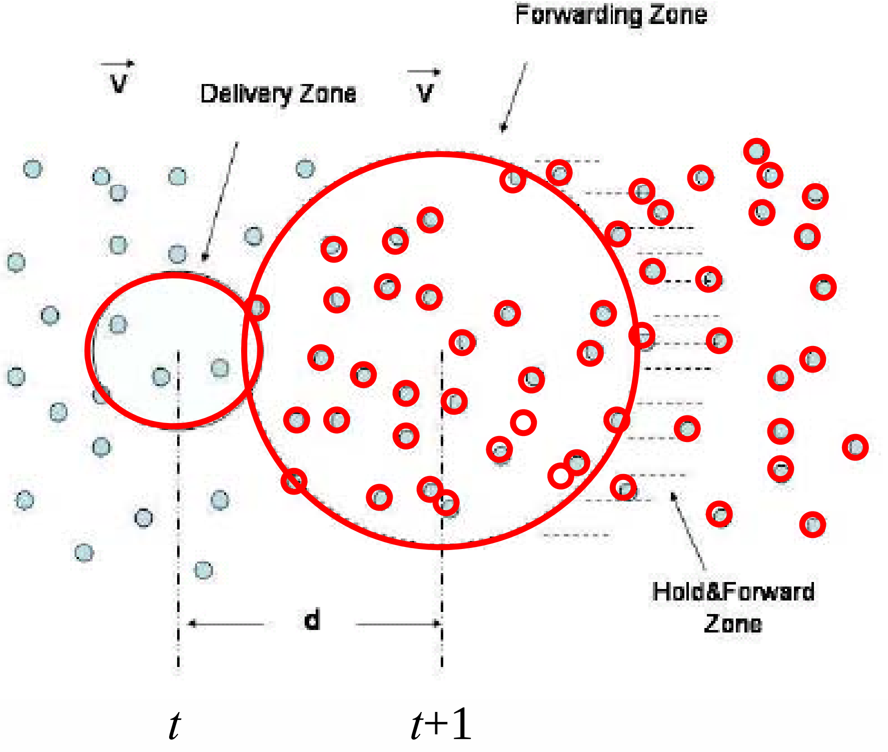
VE-Mobicast: A Variant-Egg-Based Mobicast Routing Protocol in Sensornets

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.

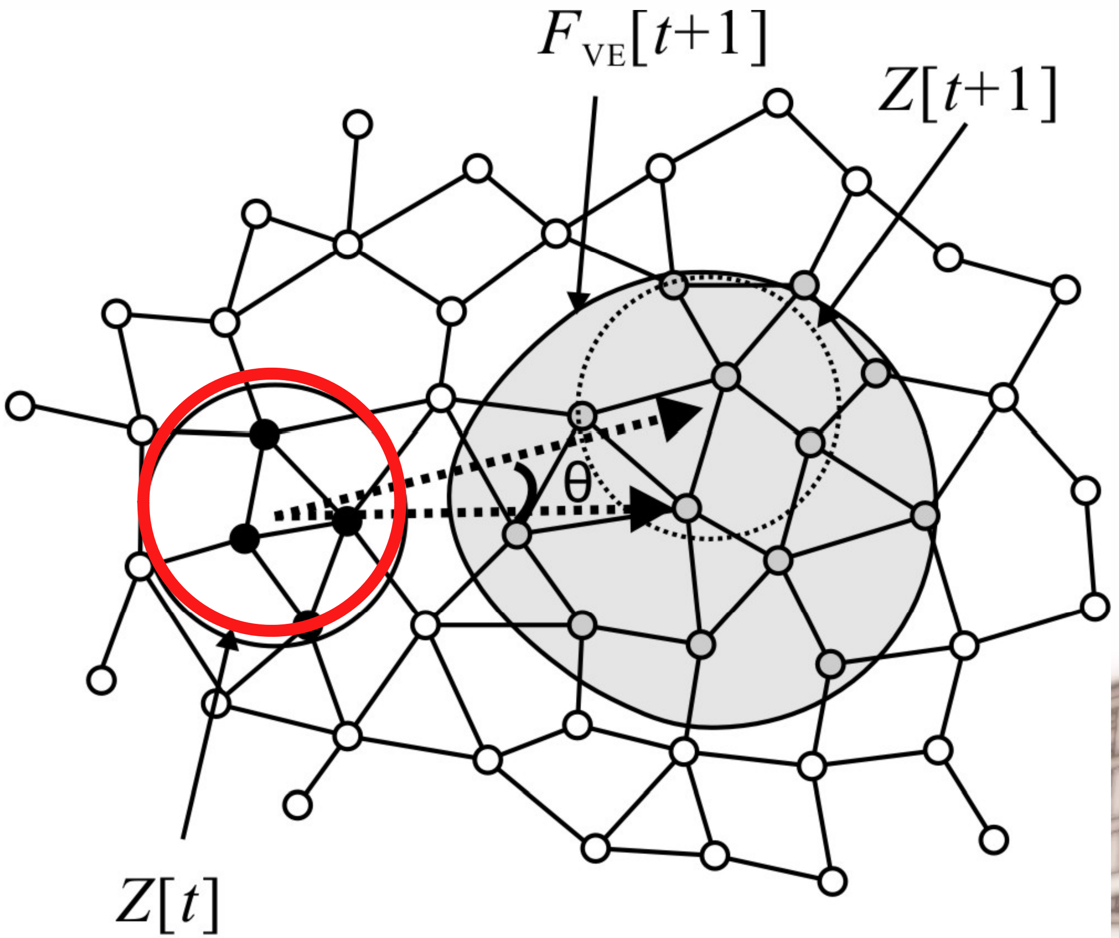
Mobicast framework



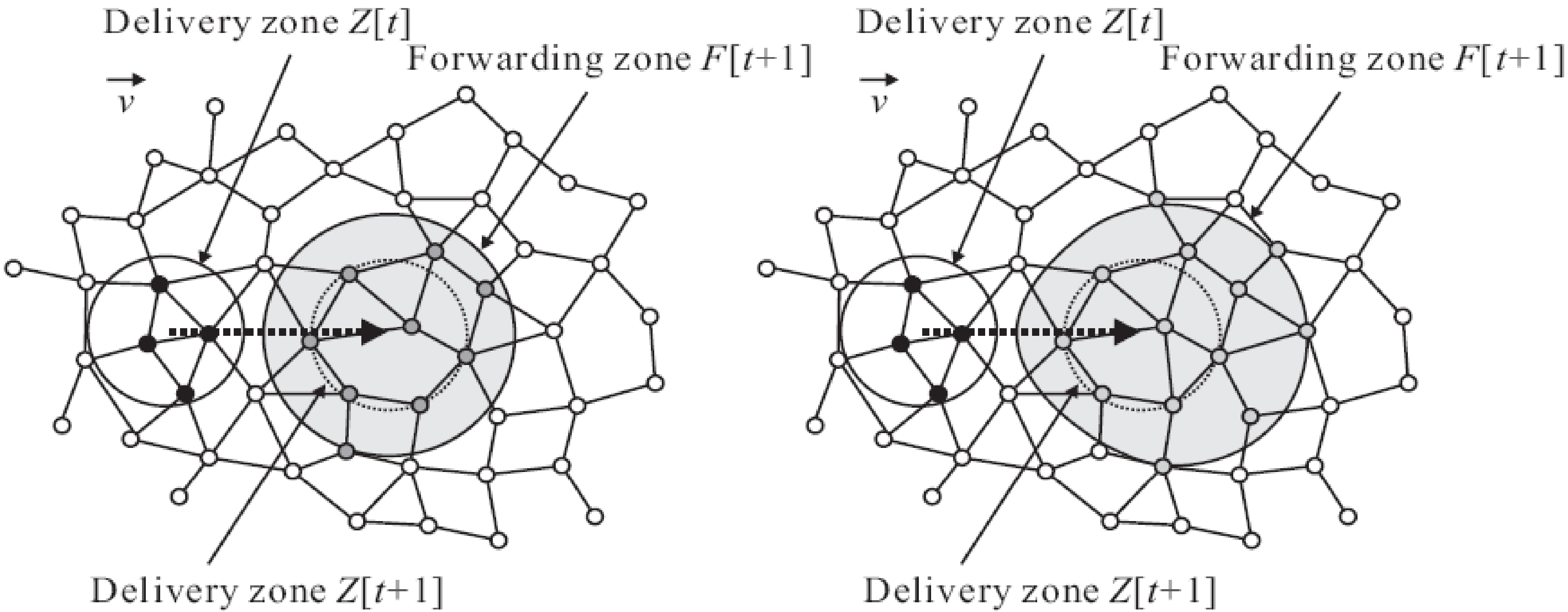
Motivation

- 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

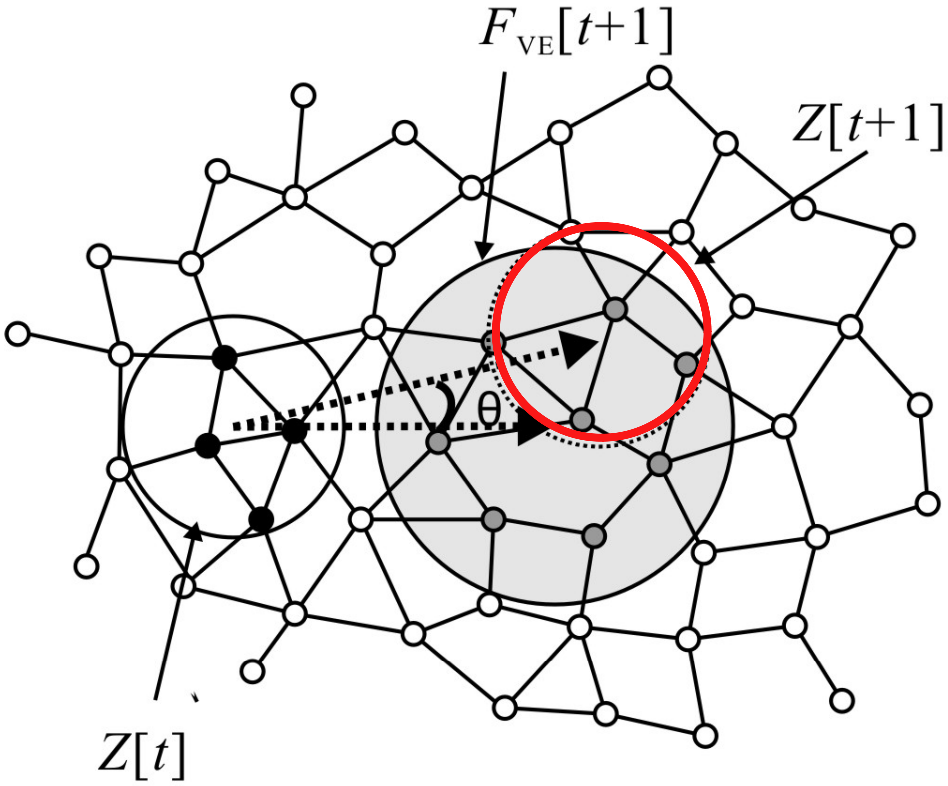


Spatiotemporal multicast and VE-mobicast

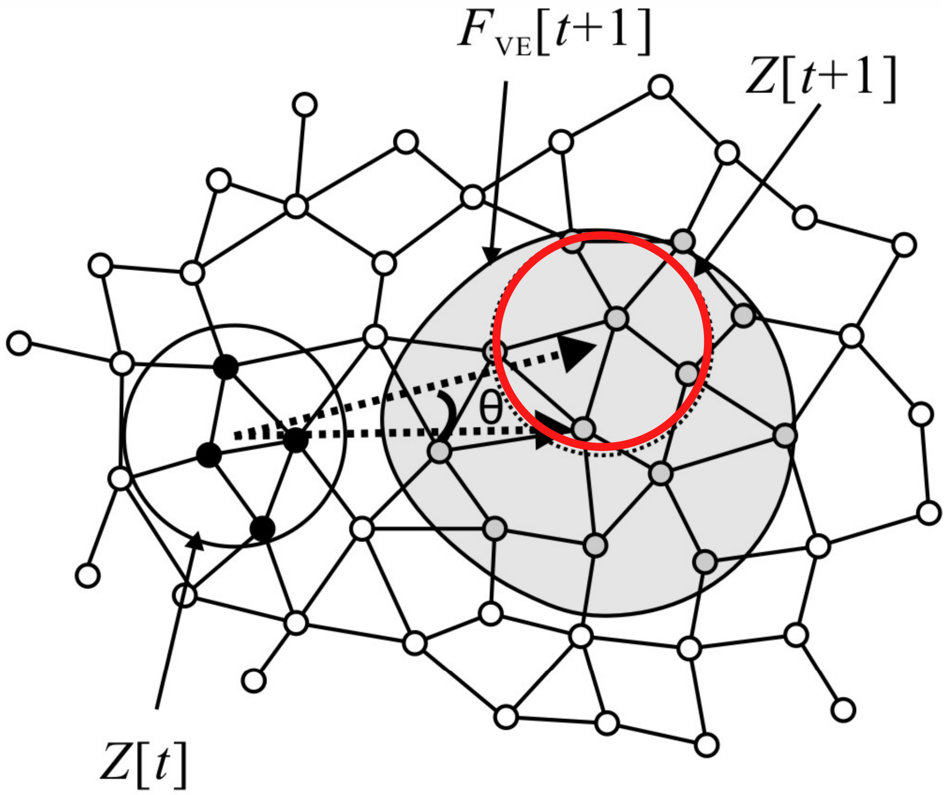


(a) (b)

High predictive accuracy

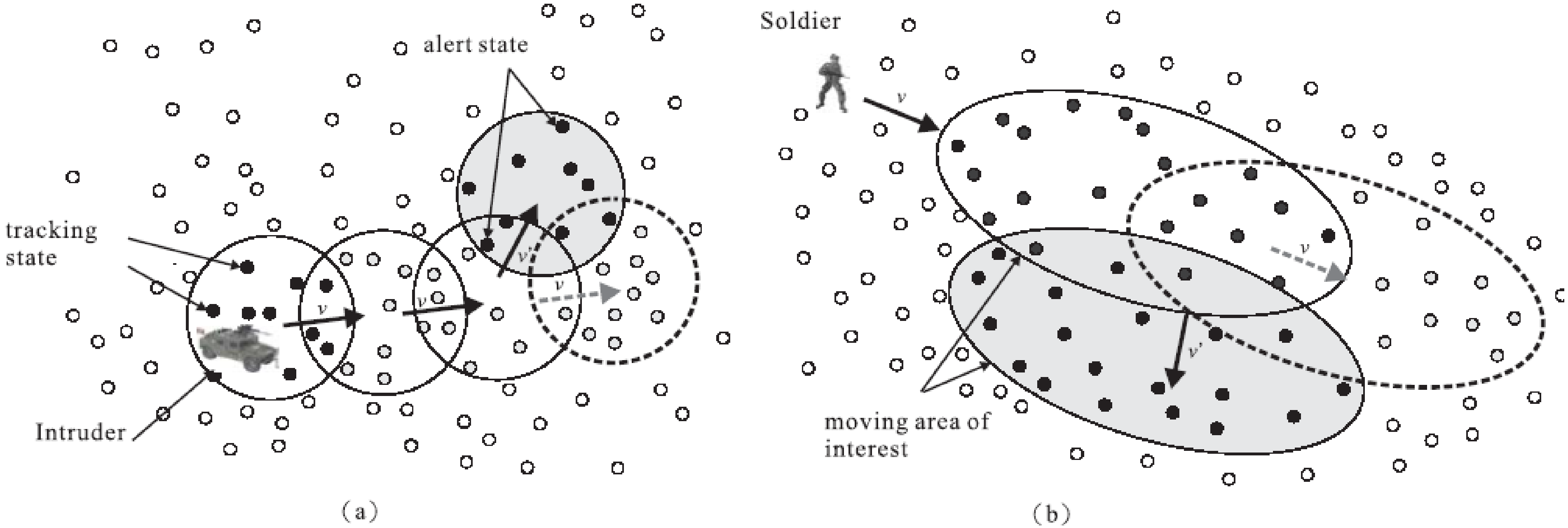


(a)



(b)

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.

Cont.

- 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.

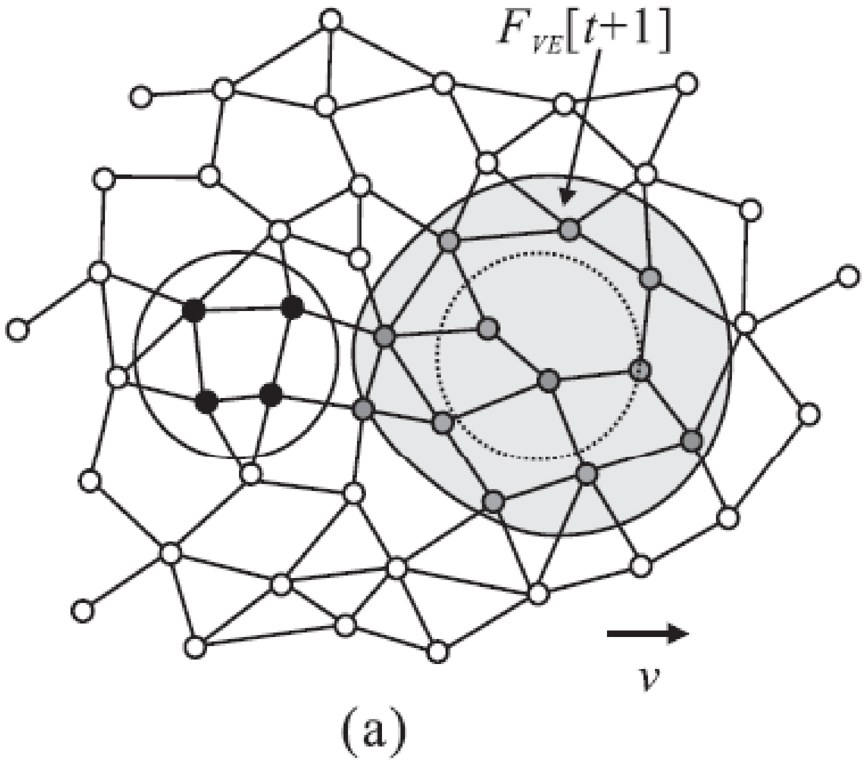
Contribution

- To simultaneously consider the factors of moving speed an 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

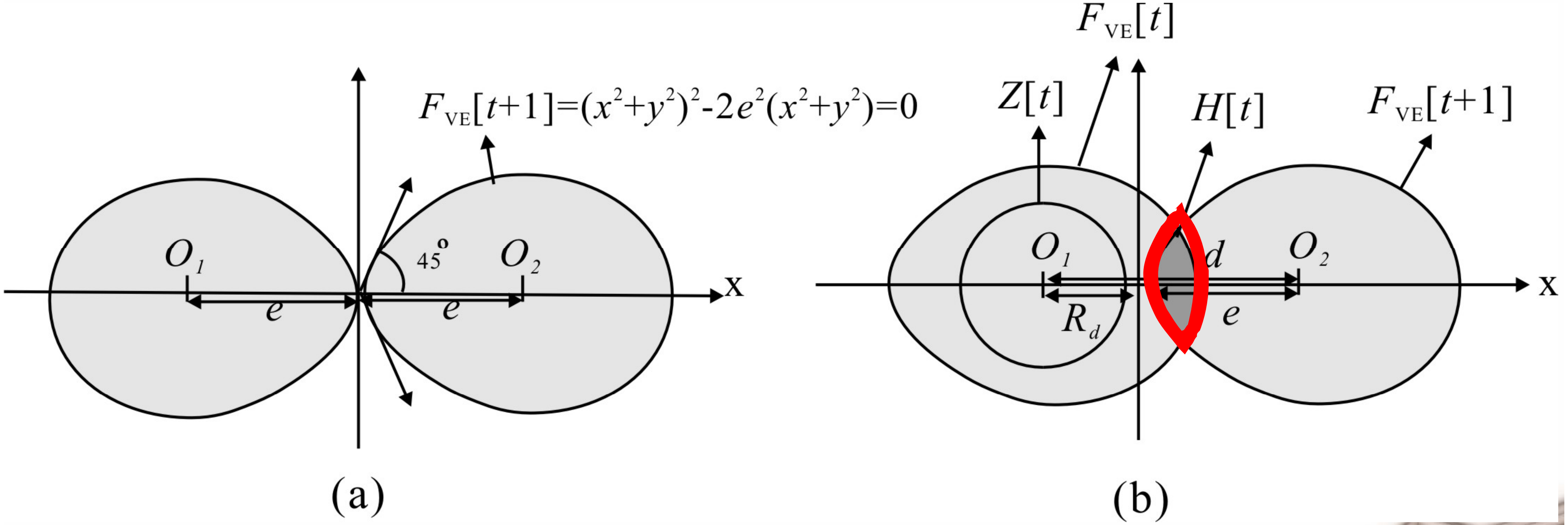
Dynamic size and shape of $F_{VE}[t+1]$



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



The oval of Cassini

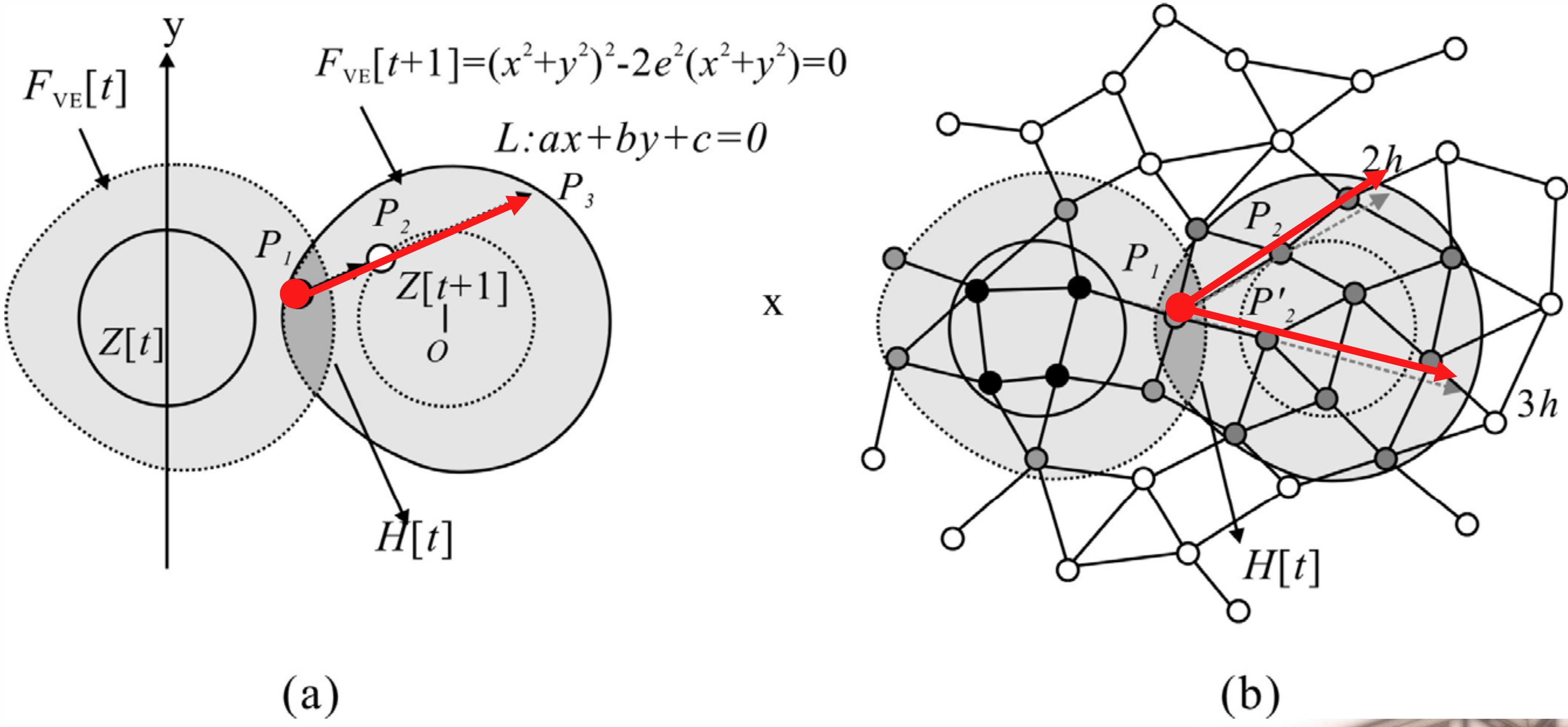
Phase I: Egg estimation phase

- 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 $F_{VE}[t+1]$
  - $H[t]=F_{VE}[t]\cap F_{VE}[t+1]$

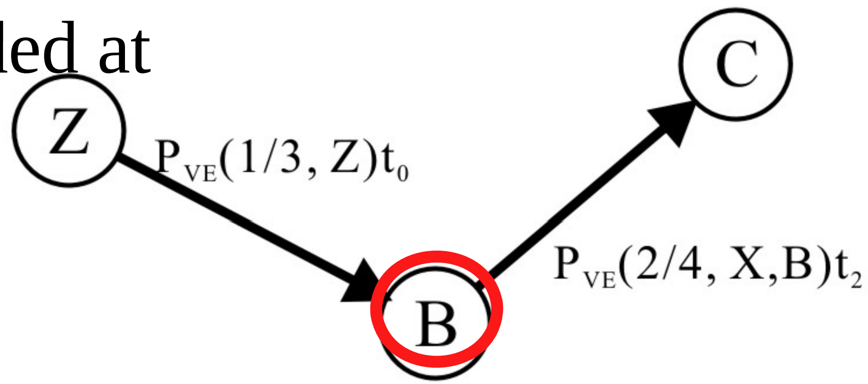
Example of phase I



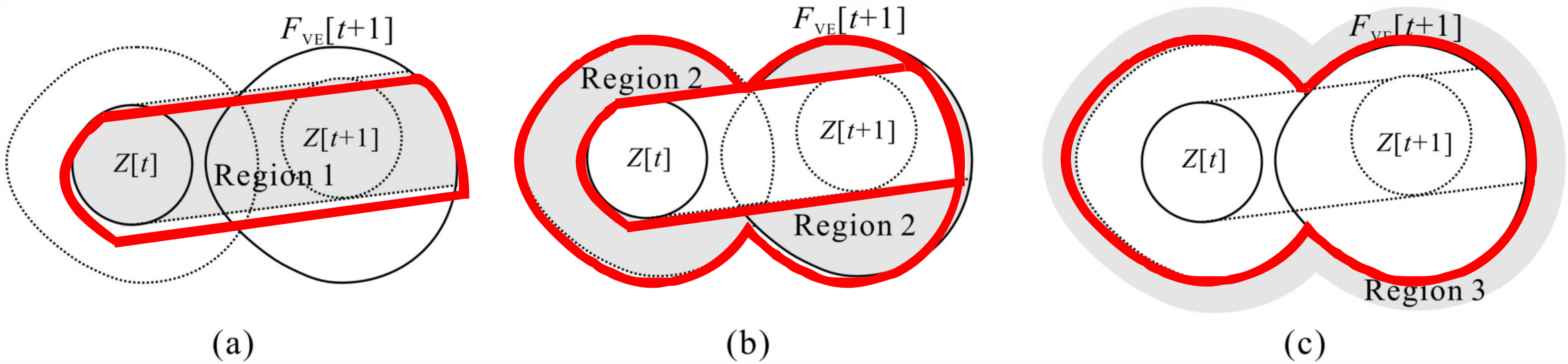
- P_1 forward message through P_2 within $\boldsymbol{H} = \frac{\overline{P_2P_3}}{r} + 1$

Phase II: **Distributed** variant-egg-based mobicast phase

- Control packet $P_{VE}(\frac{h}{H}, N_{11}, N_{12}, \ldots, N_{1j})_{t_i}$
  - $\frac{h}{H}$ 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 $t_x = t_y + \boldsymbol{d} + backoff\_time$



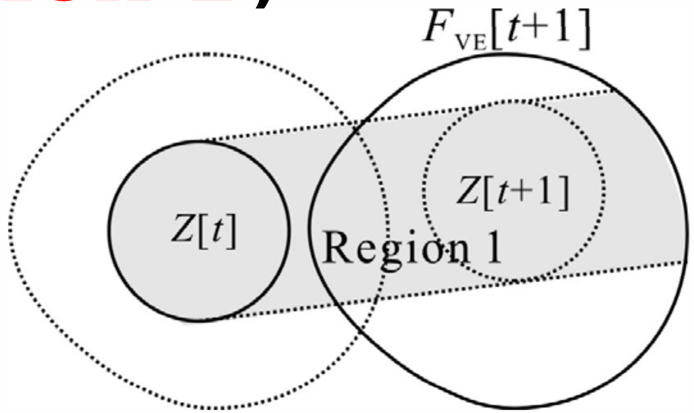
Three different regions

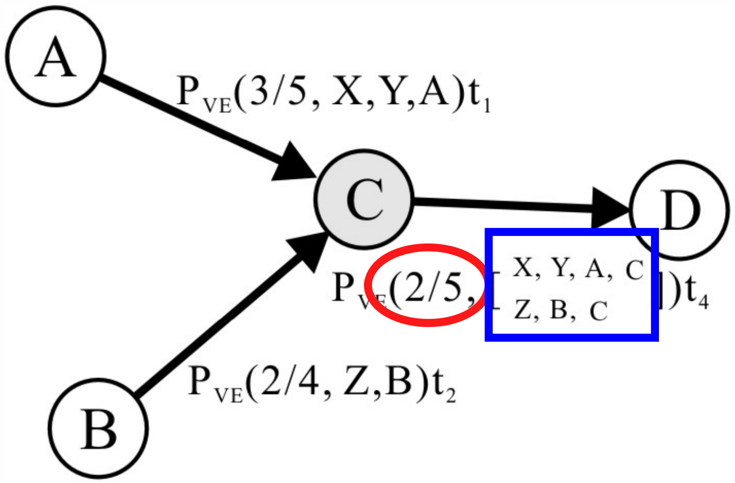


- Let $\dfrac{h_{merge}}{H_{merge}} = \dfrac{\min_{1 \le i \le m} h_i}{\max_{1 \le i \le m} H_i}$, if P is in region 1
- Let $\dfrac{h_{merge}}{H_{merge}} = \dfrac{\min_{1 \le i \le m} h_i}{\min_{1 \le i \le m} H_i}$, if P is in region 2
- Let $\dfrac{h_{merge}}{H_{merge}} = \dfrac{\max_{1 \le i \le m} h_i}{\min_{1 \le i \le m} H_i}$, if P is in region 3

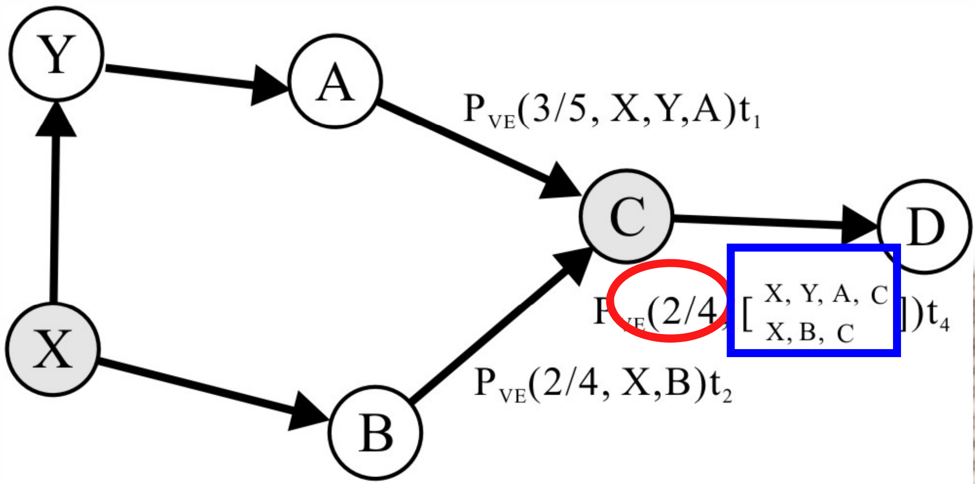
Example of **merging** operation (Region 1)

$$\frac{h_{merge}}{H_{merge}} = \frac{\min_{1 \le i \le m} h_i}{\max_{1 \le i \le m} H_i}$$





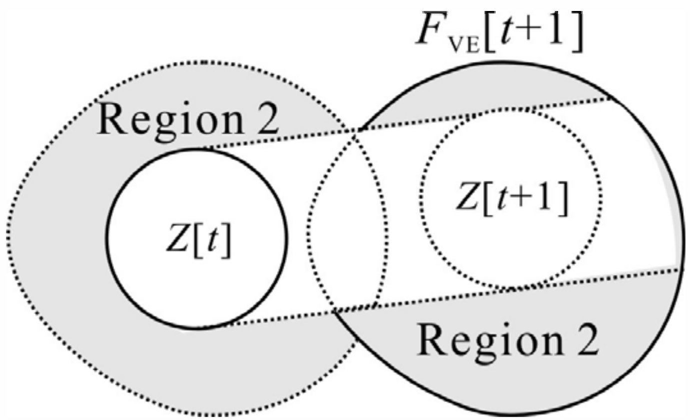
(a) Region 1

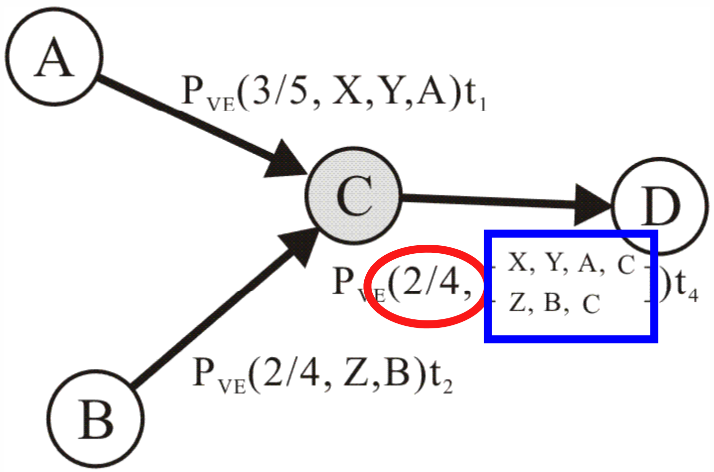


(d) Region 1

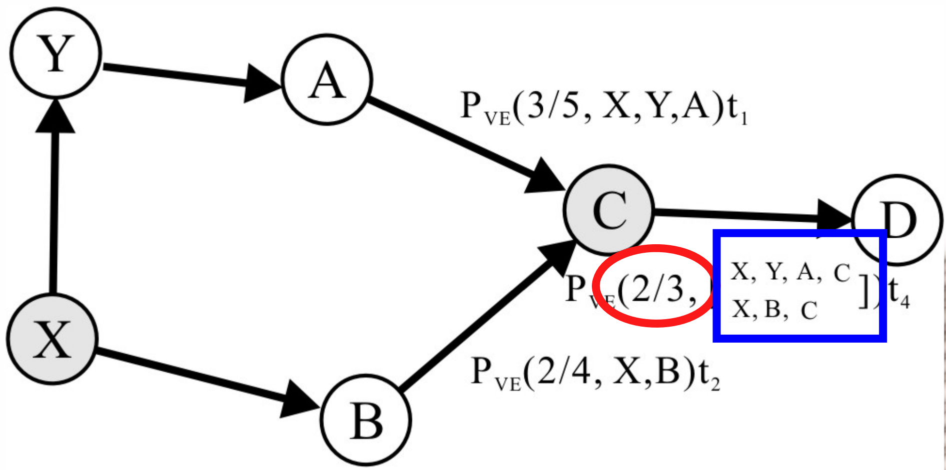
Example of merging operation (Region 2)

$$\frac{h_{merge}}{H_{merge}} = \frac{\min_{1 \le i \le m} h_i}{\min_{1 \le i \le m} H_i}$$





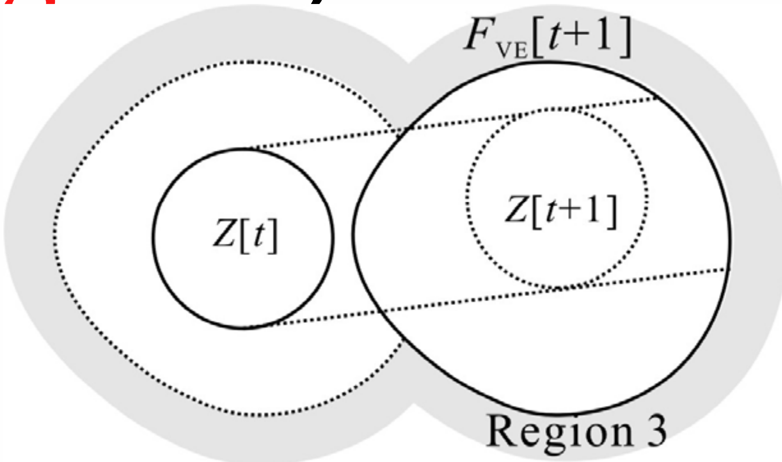
(b) Region 2

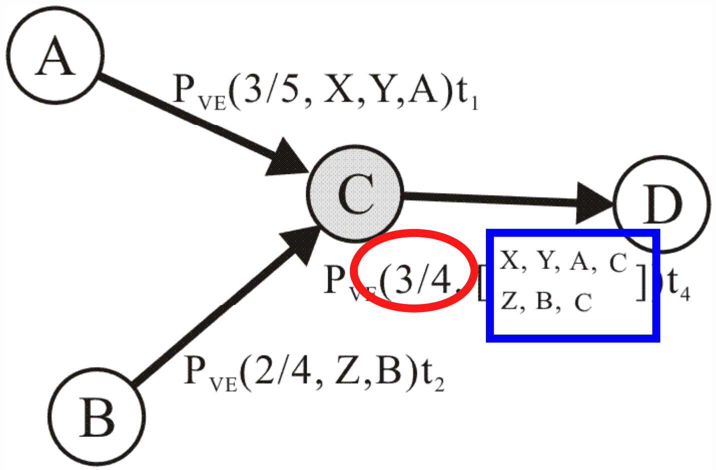


(e) Region 2

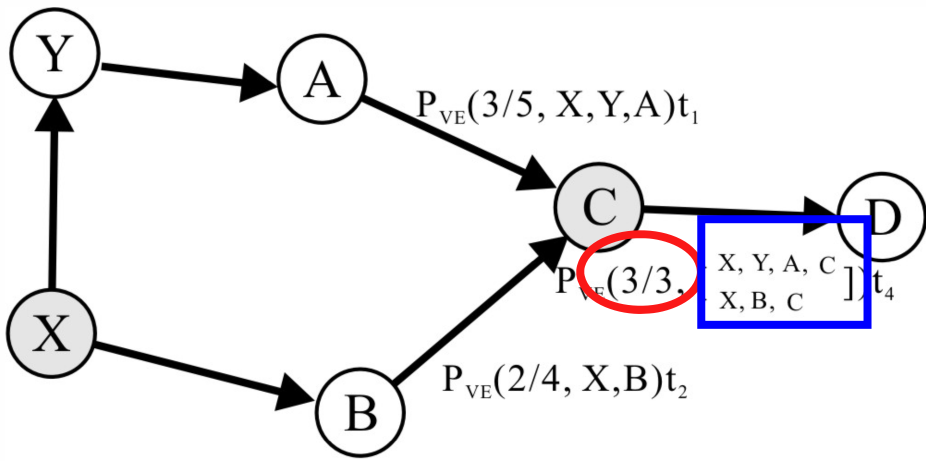
Example of merging operation (Region 3)

$$\frac{h_{merge}}{H_{merge}} = \frac{\max_{1 \le i \le m} h_i}{\min_{1 \le i \le m} H_i}$$



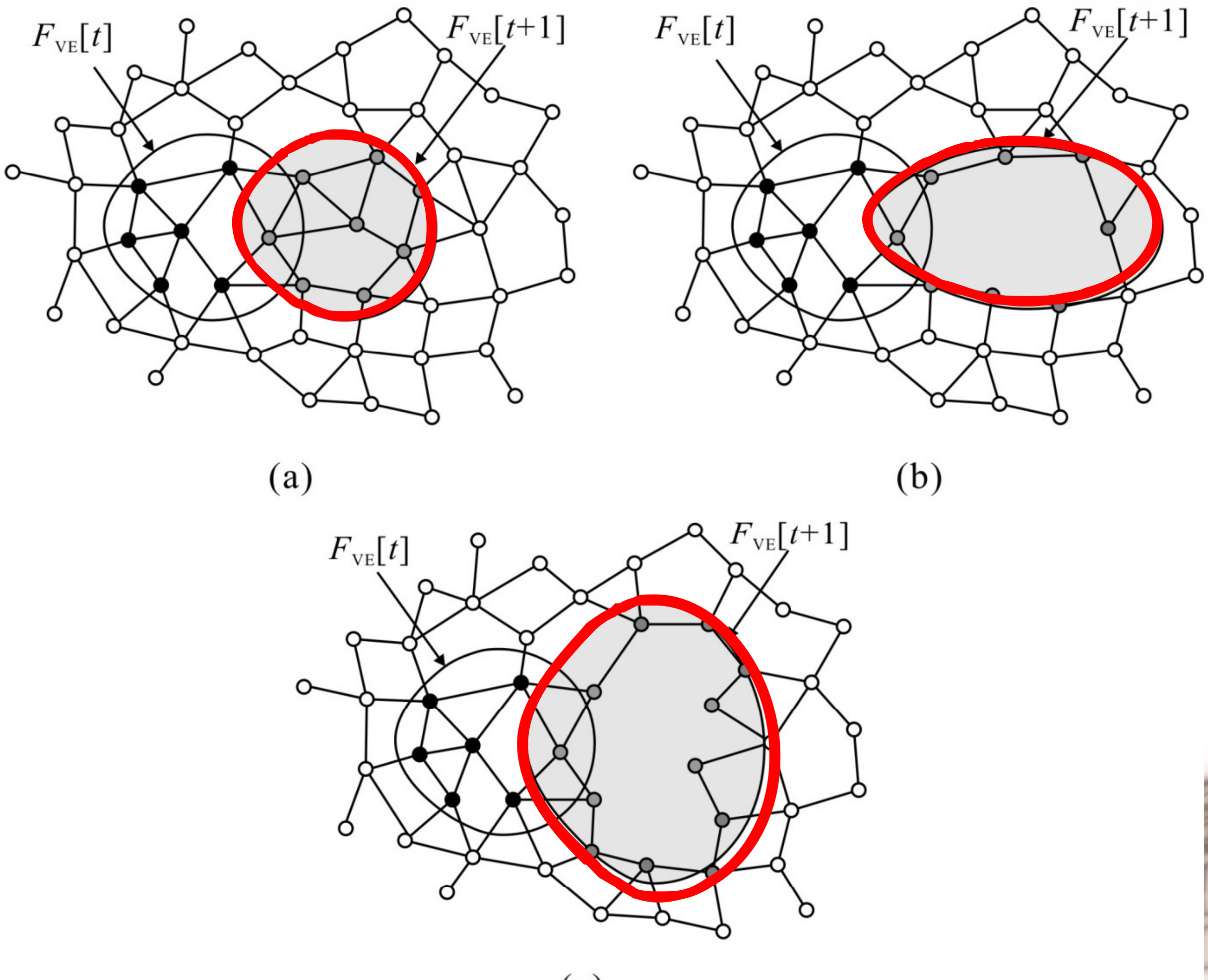


(c) Region 3



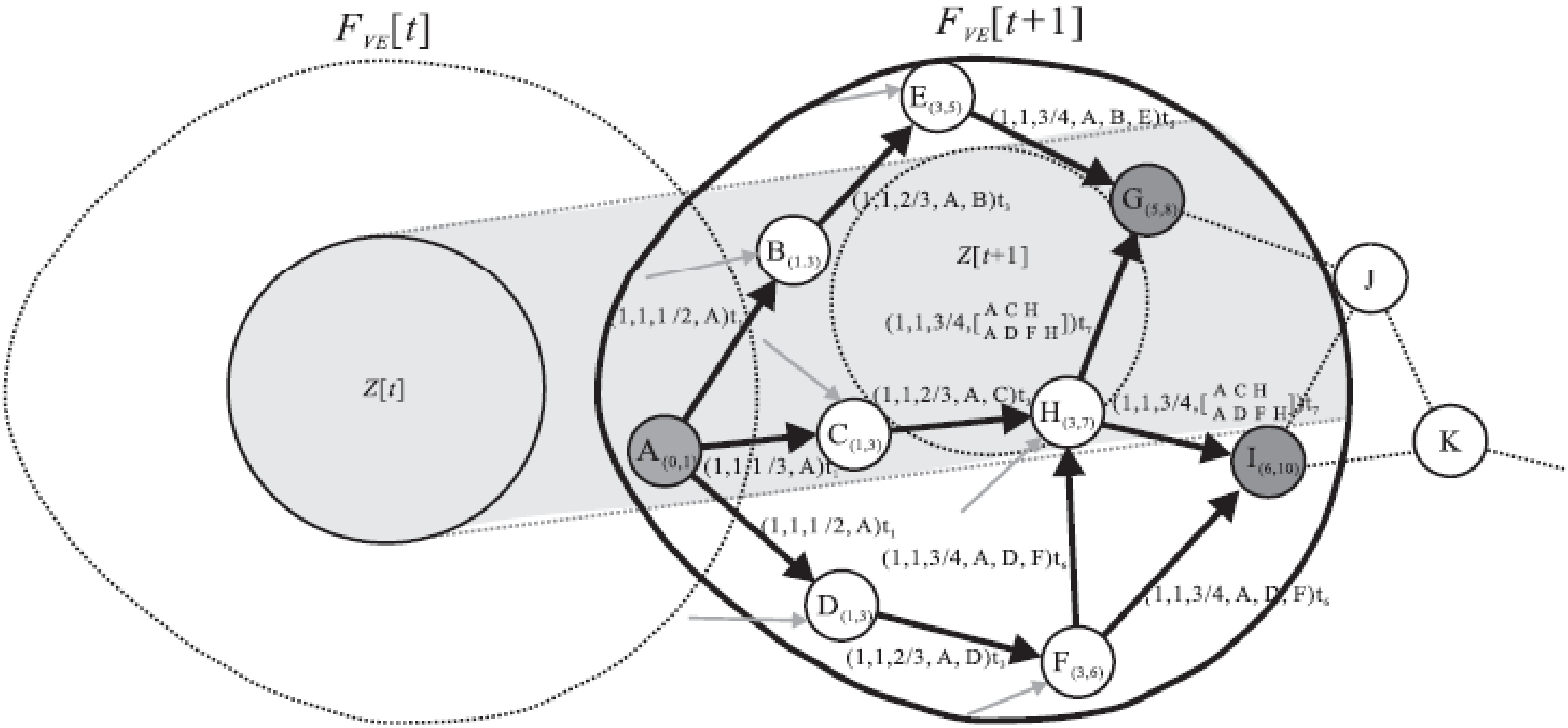
(f) Region 3

Dynamic size and shape of $F_{VE}[t+1]$

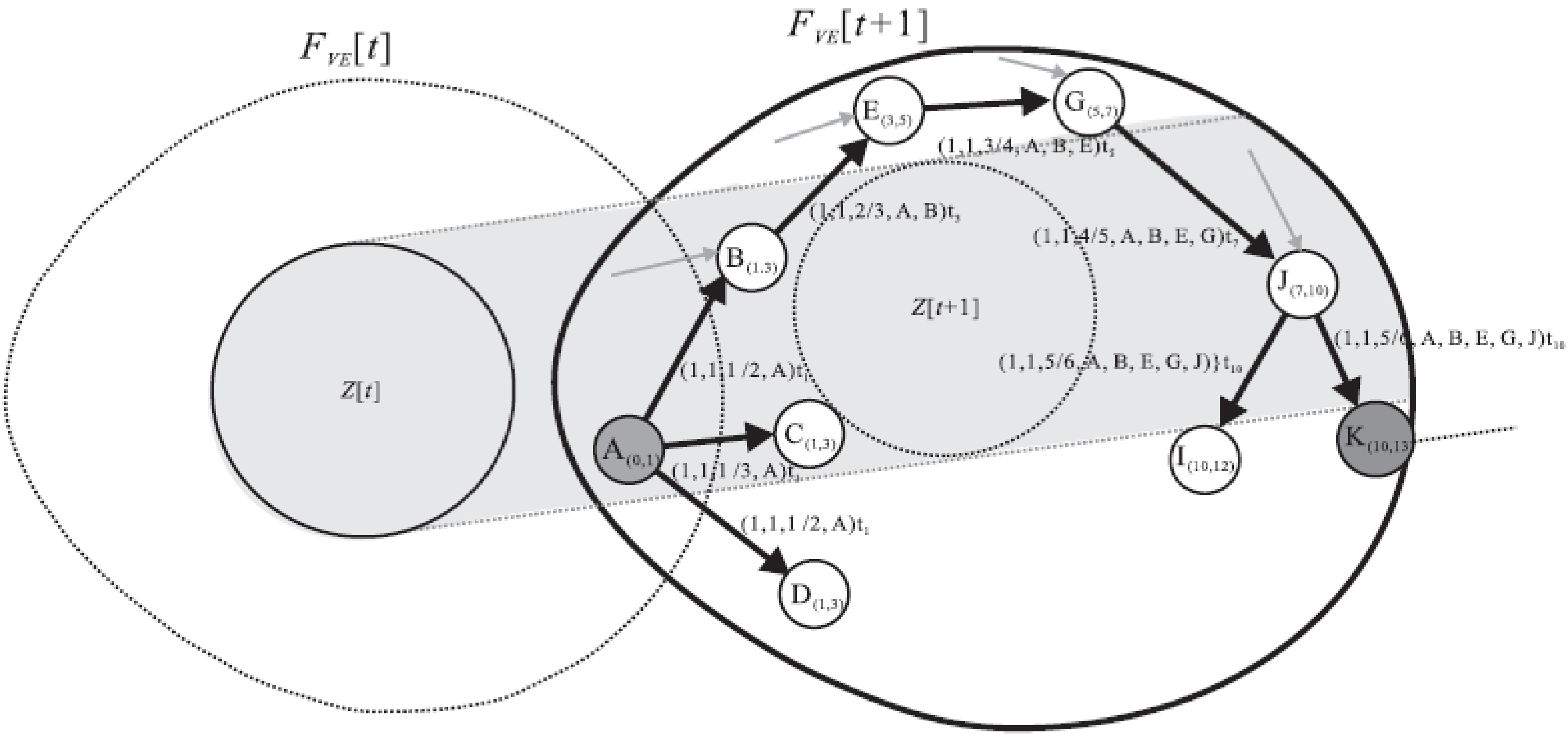


(c)

Scenario of the no ”hole” problem



Scenario of the ”hole” problem



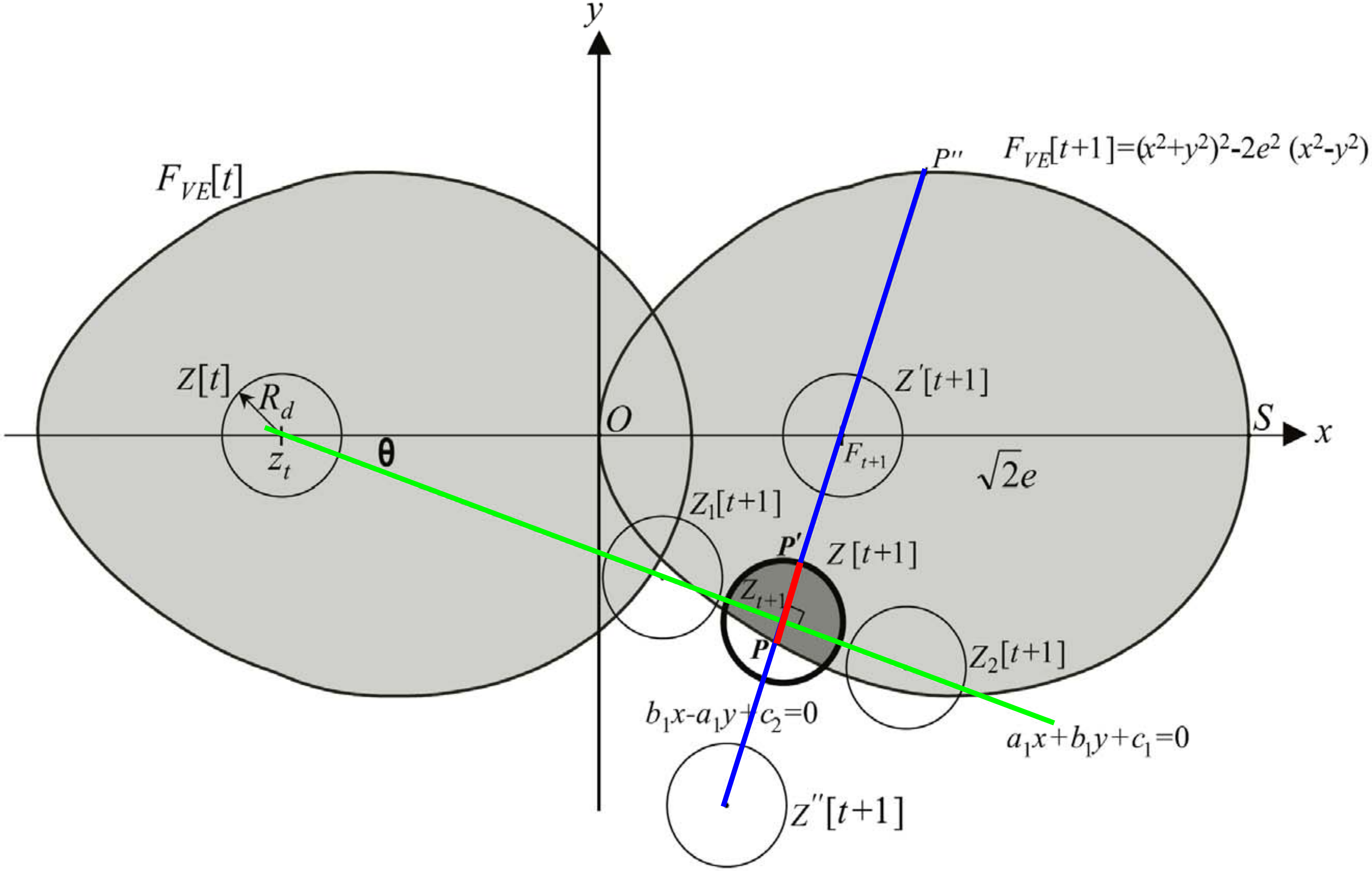
Performance analysis

- 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 low bound of the predictive accuracy, denoted as* RA_{low_bound}, *is* $\frac{2\int_{R_d-\left|\overline{PP'}\right|}^{R_d}\sqrt{{R_d}^2-x^2}dx}{\pi {R_d}^2}$ *for* $0 < \left|\overline{PP'}\right| = R_d - (\left|\overline{F_{t+1}Z_{t+1}}\right| - \left|\overline{F_{t+1}P}\right|) < 2R_d$, *where* P *is the intersection point of line* $b_1x - a_1y + c_2 = 0$ *and* $F_{VE}[t+1]$, P' *is the intersection point of line* $b_1x - a_1y + c_2 = 0$ *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

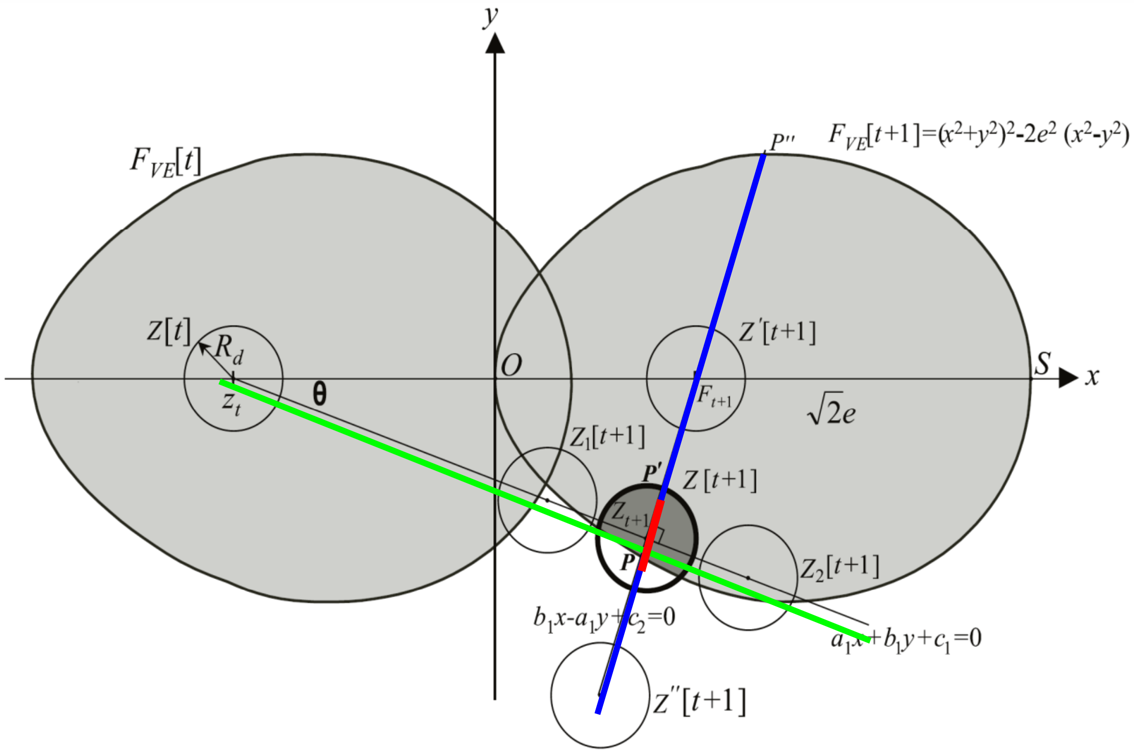


Low Bound of Predictive Accuracy

$$RA_{low\_bound}$$

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

$$= \frac{2\int_{R_d-\left|\overline{PP'}\right|}^{R_d} \sqrt{R_d{}^2 - x^2}\,dx}{\pi R_d{}^2}$$



Lemma 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.*

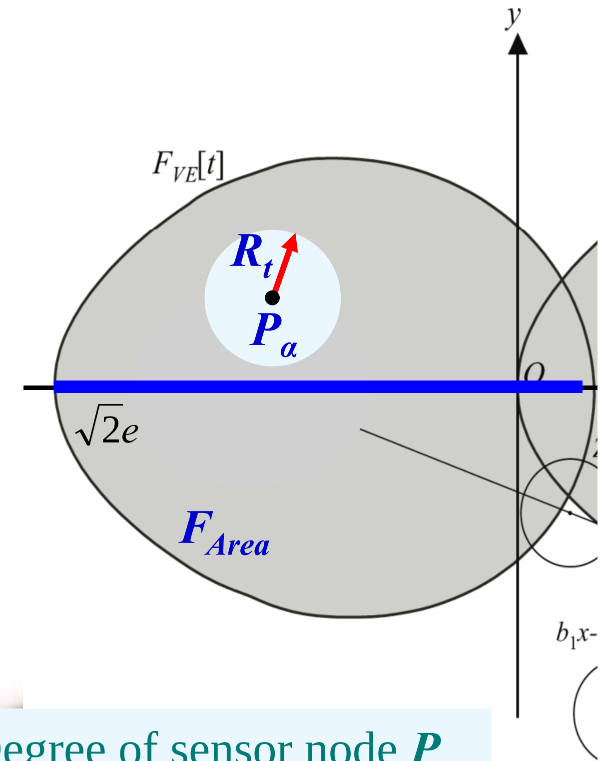
Low Bound of Energy Consumption

$$F_{Area} = \int_0^{\sqrt{2}e} (x^2+y^2)^2 - 2e^2(x^2-y^2)\,dxdy$$

$$N_{total} = \frac{F_{Area}}{Rt^2}$$

Transmission range

$$= \frac{\int_0^{\sqrt{2}e} (x^2+y^2)^2 - 2e^2(x^2-y^2)\,dxdy}{Rt^2}$$



The low bound of energy consumption

$$\sum_{\alpha=1}^{N_{total}} \left(P_t + (d_{P_\alpha} - 1)P_r + P_{switch}\right)$$

Degree of sensor node P_α

$$\approx N_{total} \times \left(P_t + (d-1)P_r + P_{switch}\right)$$

Average degree of sensor nodes

Lemma 3.

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

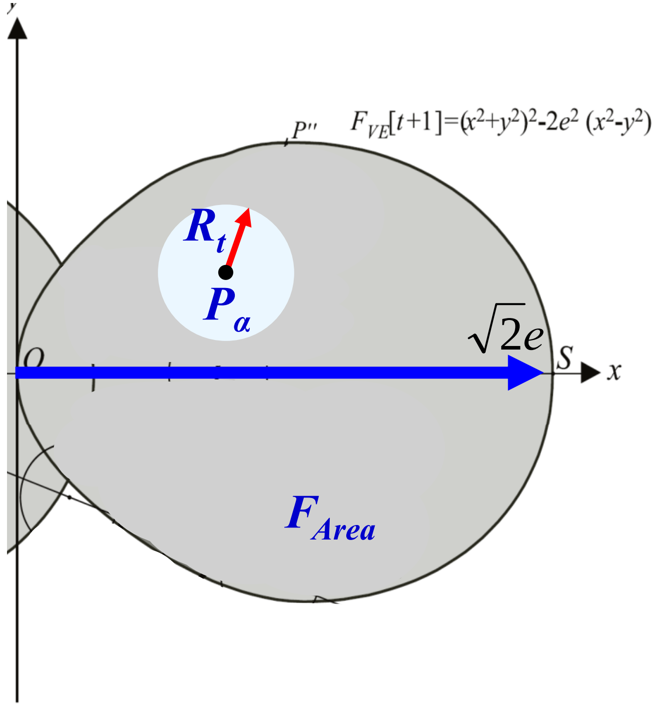
Total Number of Mobicast Messages

$$F_{Area} = \int_0^{\sqrt{2}e} (x^2+y^2)^2 - 2e^2(x^2-y^2)\,dxdy$$

$$N_{total} = \frac{F_{Area}}{Rt^2}$$

Transmission range (Rt)

$$= \frac{\int_0^{\sqrt{2}e} (x^2+y^2)^2 - 2e^2(x^2-y^2)\,dxdy}{Rt^2}$$



Total Number of Mobicast Messages

Average degree of sensor nodes (d)

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

Degree of sensor node P_α (d_{P_α})

Lemma 4.

Lemma 4 *The running time of the VE-mobicast protocol from time t to $t+1$ is* $(\frac{\sqrt{2}e}{R_t} - 1) \times ((d-1)T_r + T_b)$*, where* $\frac{\sqrt{2}e}{R_t}$ *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.*

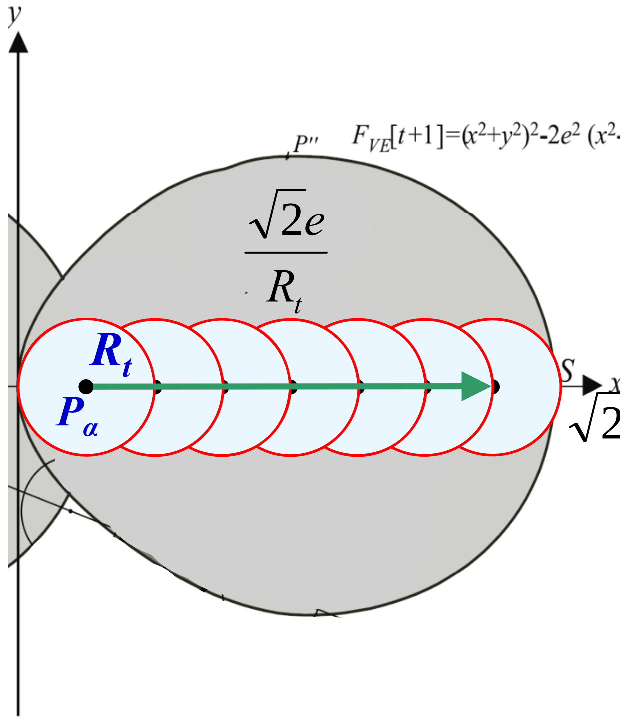
The Running Time

Time cost of data transmission

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

Random backoff time

$$\approx (\frac{\sqrt{2}e}{R_t} - 1) \times ((d-1)T_r + T_b)$$



Simulation result

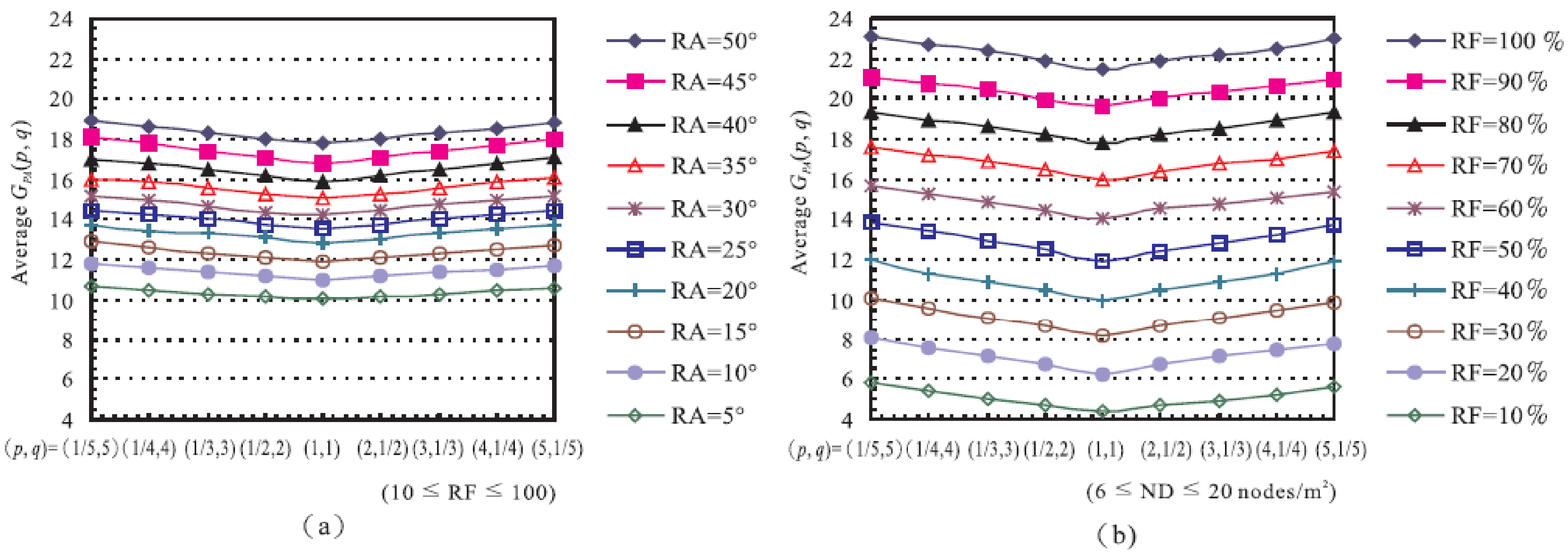
- Our paper presents a variant-egg-based mobicast protocol. To evaluate our VE-mobicast protocol (VE-mobicast), Huang *et al.*'s mobicast protocol (mobicast) [10], and the FAR protocol (FAR) [12],
  - all these protocols are mainly implemented using the NCTUns 2.0 simulator and emulator [28].
- The simulation environment
  - 1000 x 800 m^2 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 (walt)
    - 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

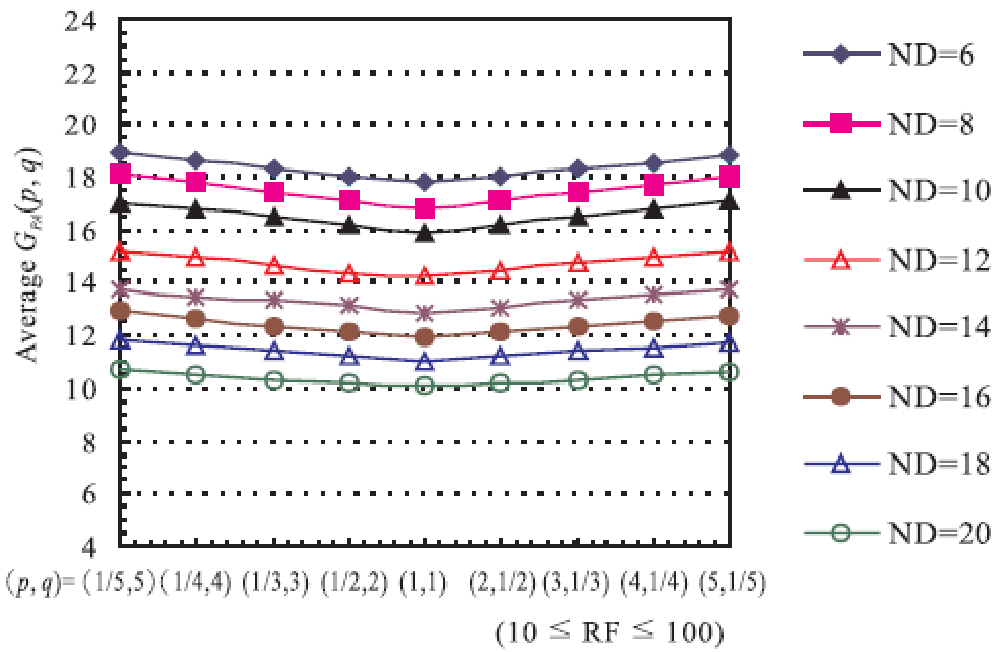
- The predictive accuracy gap is defined as $GPA(p,q) = PA_{optimal} - PA_{p,q}$, where $PA_{p,q}$ denotes the predictive accuracy (PA) under given values of p and q, where $p \times q = 1$.

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

Performance of the average predictive accuracy gap *GPA*(*p*,*q*) vs. (a) the rotation angle (10% ≤ RF ≤ 100%), (b) the rotation frequency (6 ≤ ND ≤ 20 nodes/*m*2



Performance of the average predictive accuracy gap $GPA(p,q)$ vs. (c) the network density (10% ≤ RF ≤ 100%).



(c)

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.

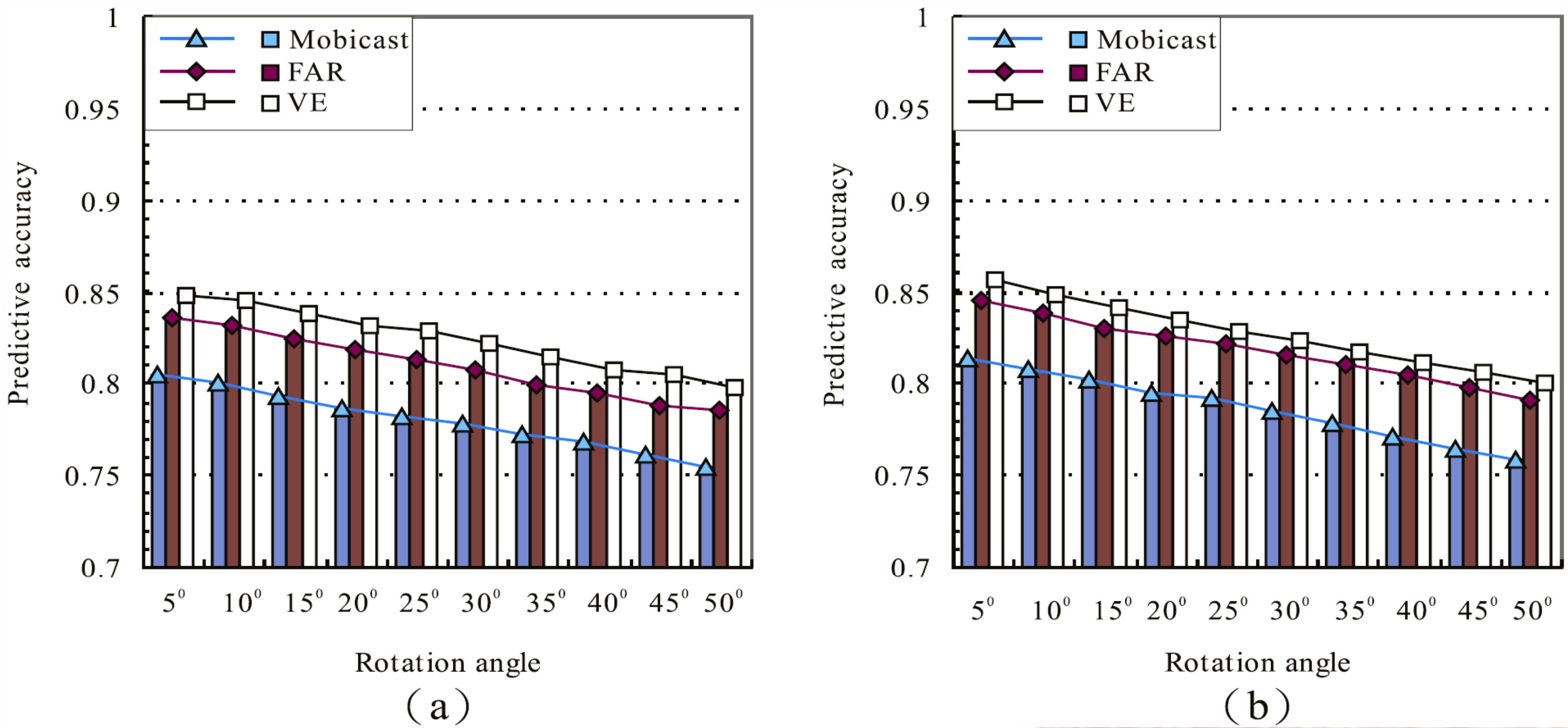
Cont.

- 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.

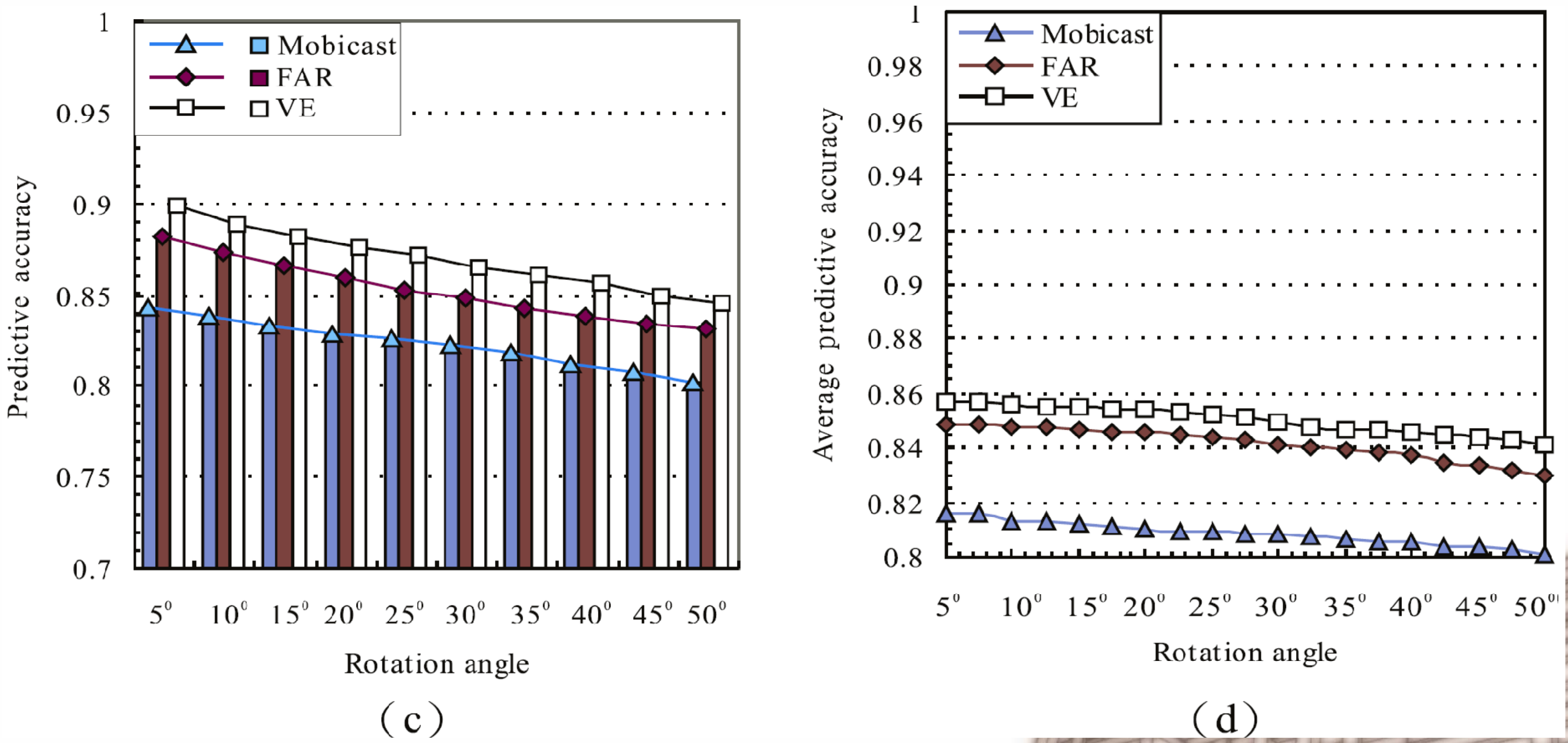
Simulation result

- 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 $F[t+1]$).

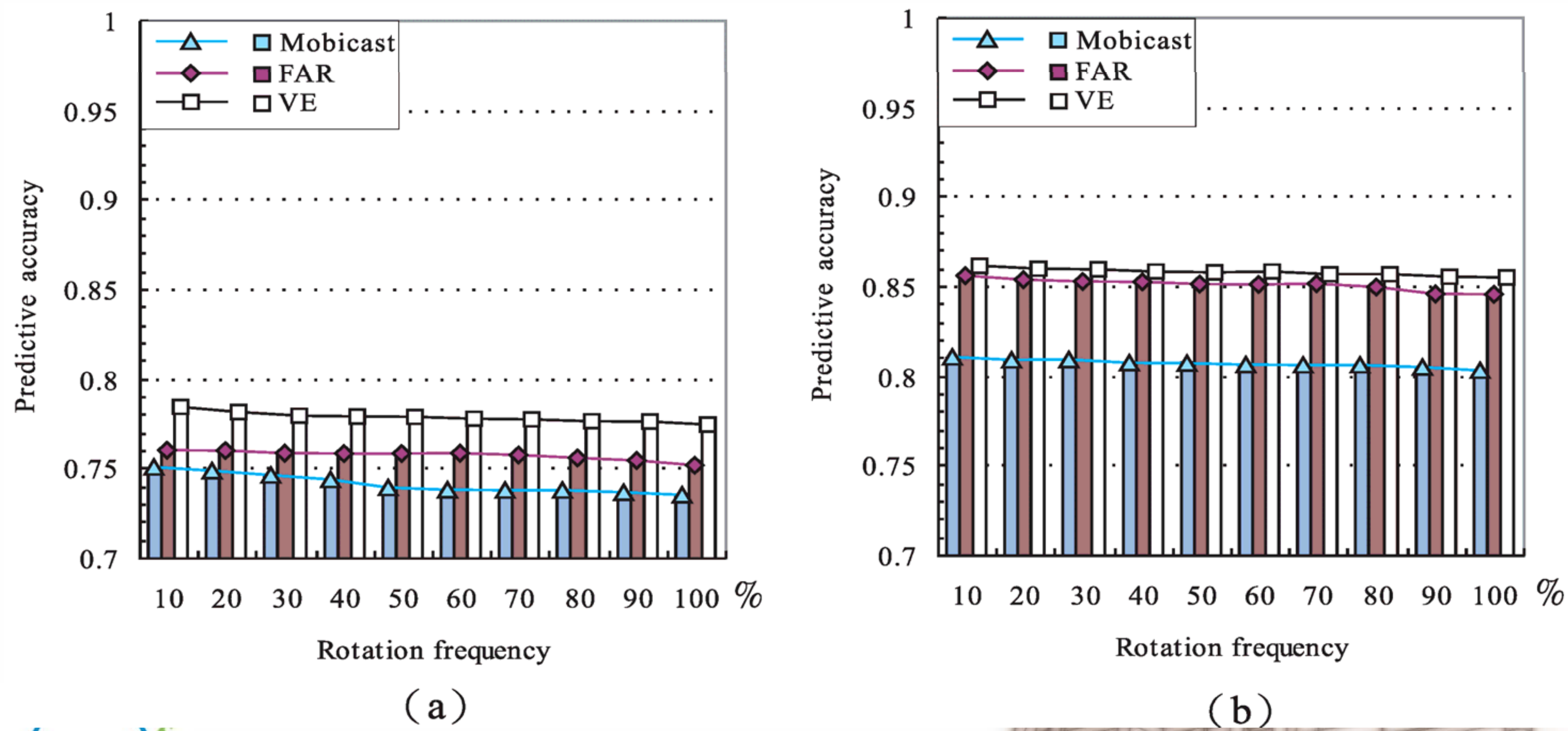
Performance of the predicitive accuracy vs. the rotation angle, where (a) the rotation frequency = 10%, (b) the rotation frequency = 50.



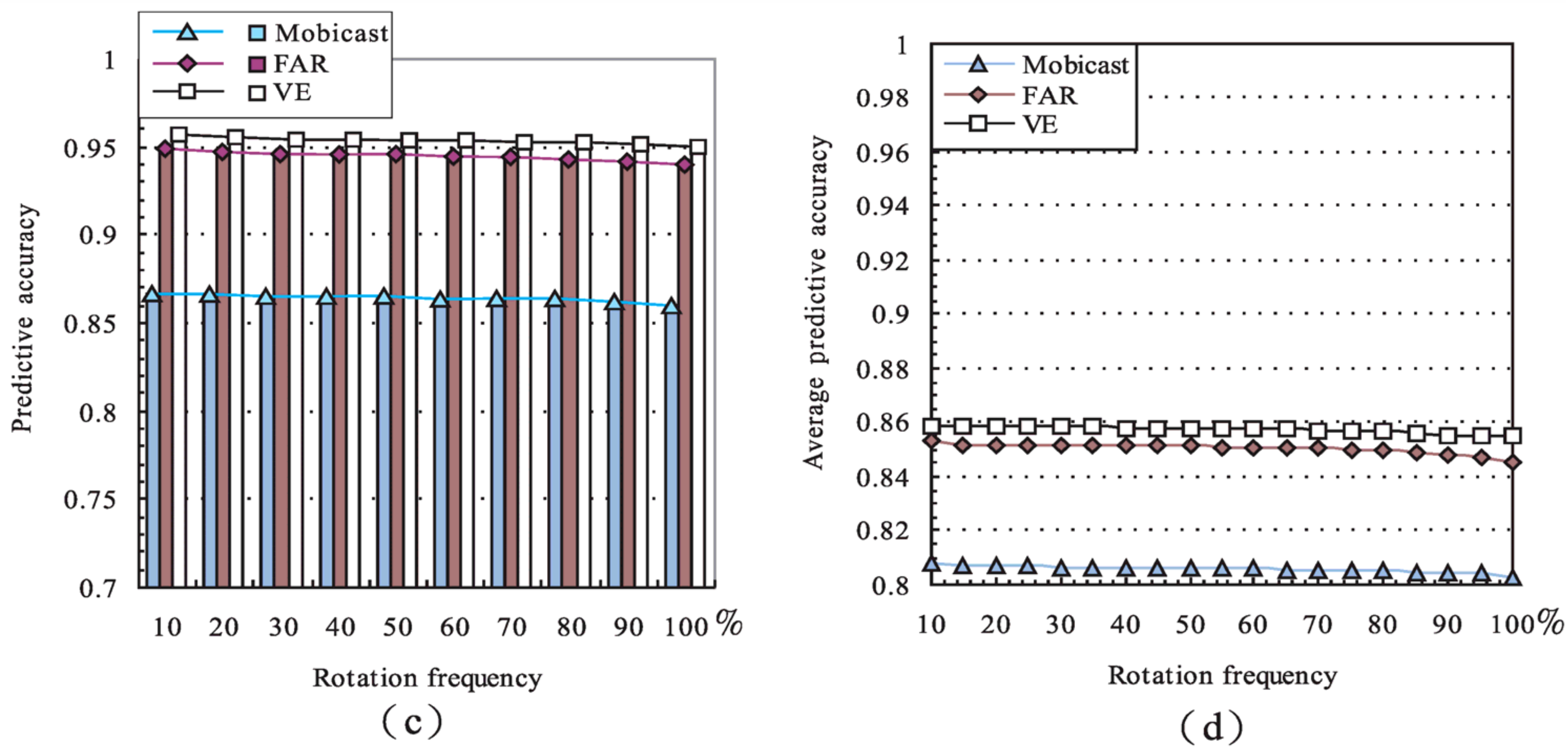
Performance of the predicitive accuracy vs. the rotation angle, where (c) the rotation frequency = 100%, and (d) 10% ≤ the rotation frequency ≤ 100%.



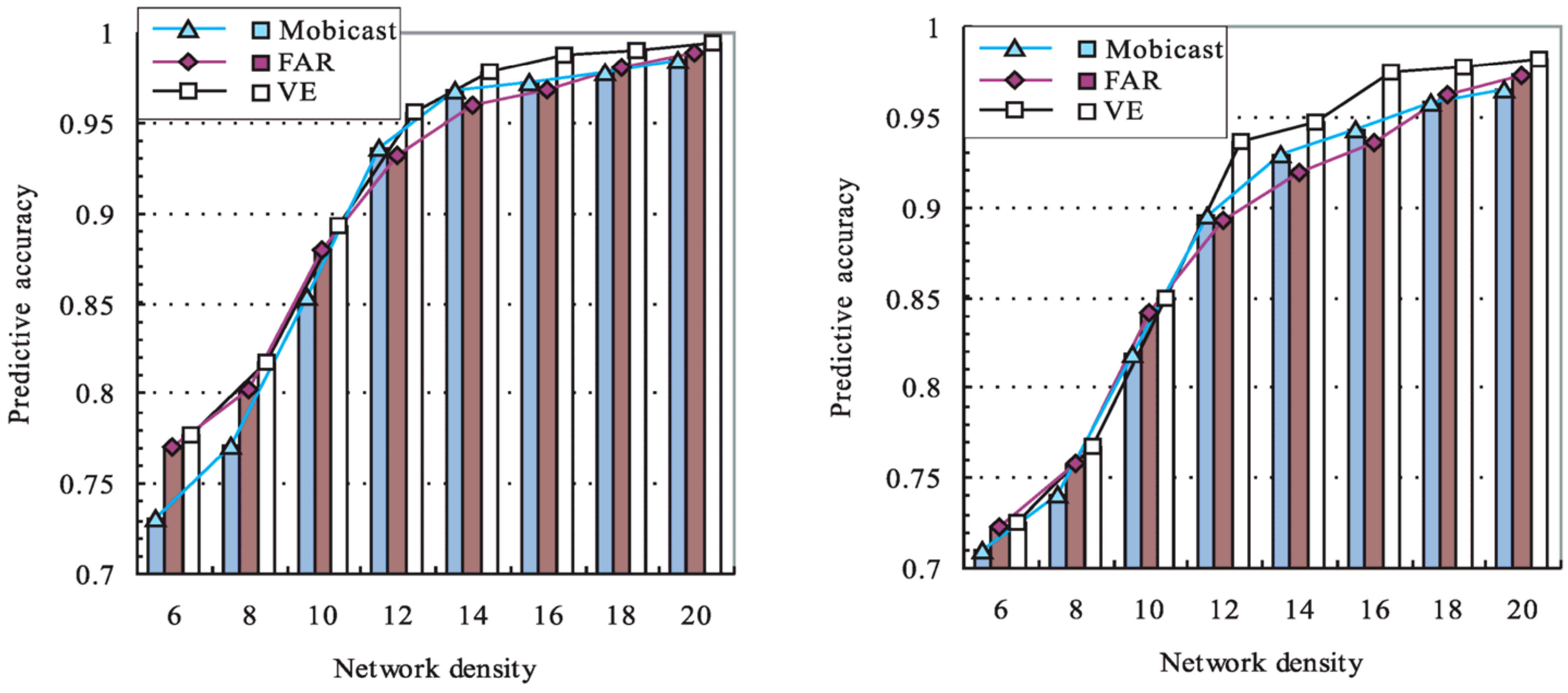
Performance of the predicitive accuracy vs. the rotation frequency, where (a) the network density = 6 nodes/m^2, (b) the network density = 12 nodes/m^2



Performance of the predicitive accuracy vs. the rotation frequency, where (c) the network density = 20 nodes/m^2, and (d) 6 nodes/$m2$ ≤ the network density ≤ 20 nodes/m^2.

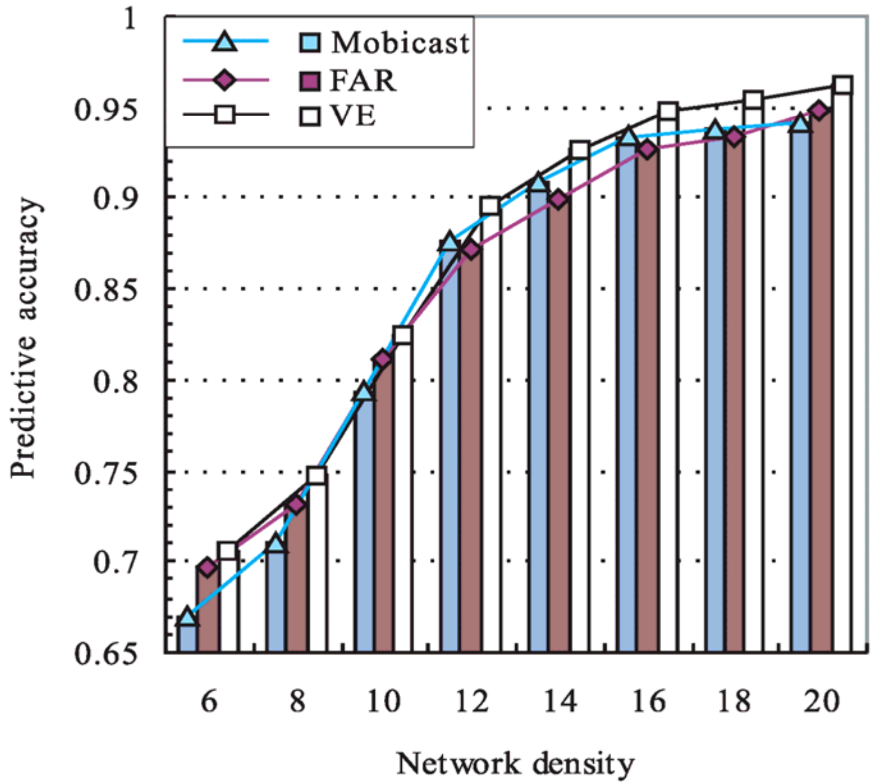


Performance of the predictive accuracy vs. the network density, when (a) the rotation angle = 5 ∘, (b) the rotation angle = 30 ∘

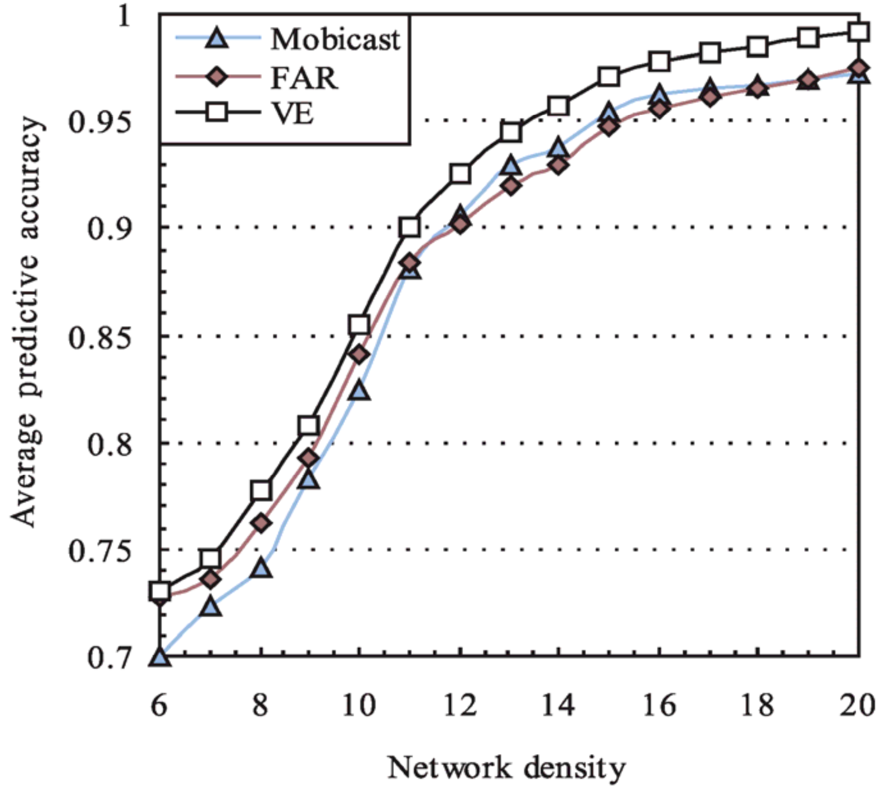


(a) (b)

Performance of the predictive accuracy vs. the network density, when (c) the rotation angle = 50 ∘, and (d) 5 ∘ ≤ the rotation angle ≤ 50 ∘



(c)

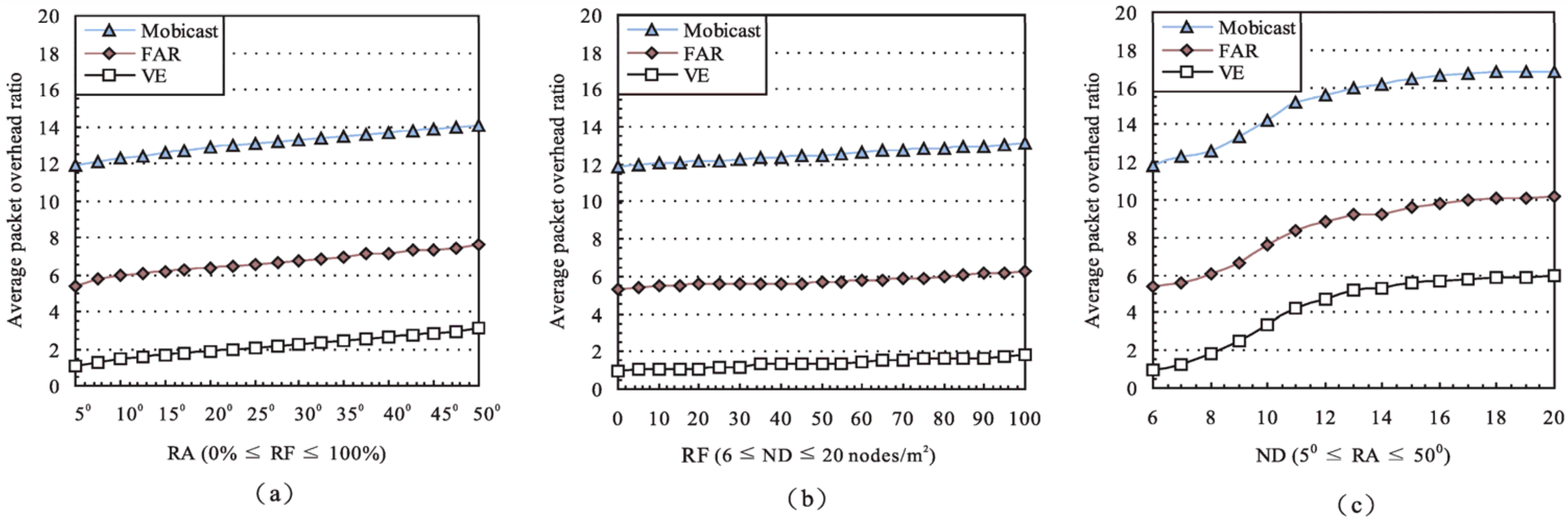


(d)

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.

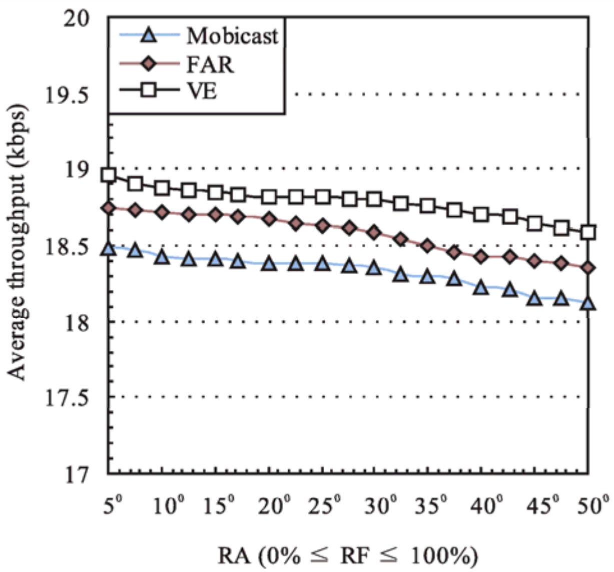
Performance of average packet overhead ratio (POR) vs. (a) rotation angle (RA), (b) rotation frequency (RF), and (c) network density (ND)



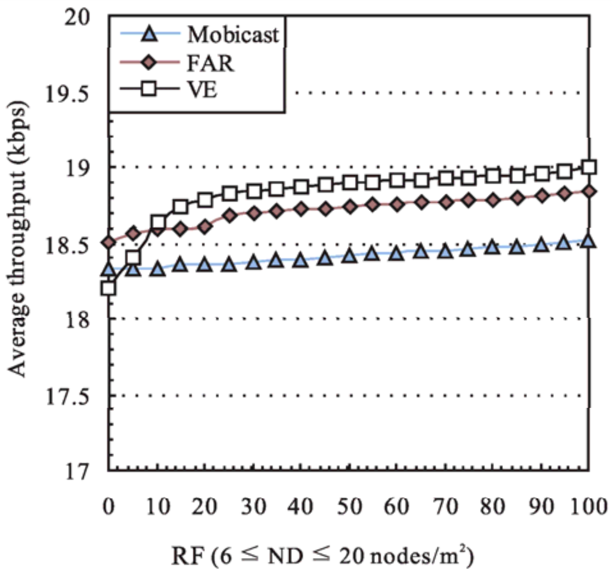
Simulation result

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

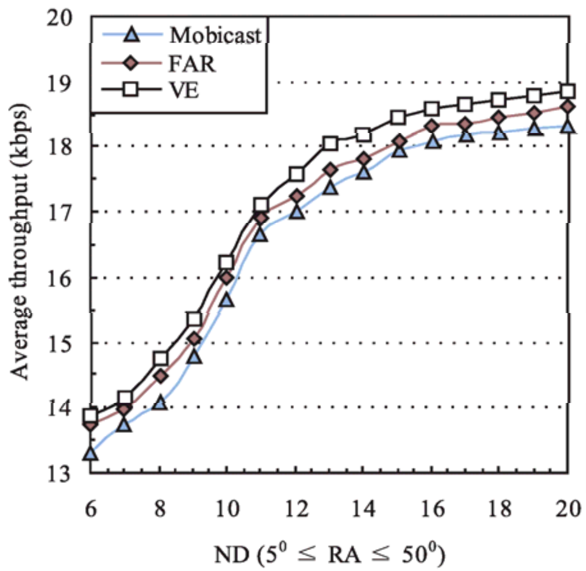
Performance of the average throughput (TP) vs. (a) rotation angle (RA), (b) rotation frequency (RF), and (c) network density (ND)



(a)



(b)

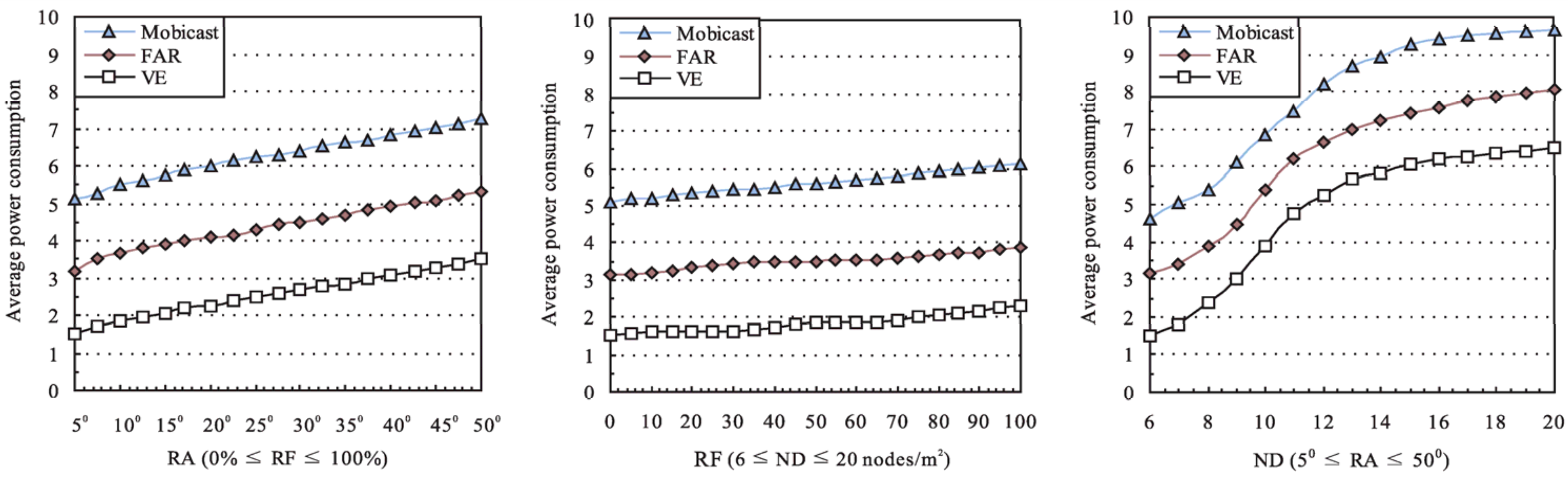


(c)

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)



(a) (b) (c)

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.

Conclusion

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