Introduction to Sensor Networks

FL07-18-1
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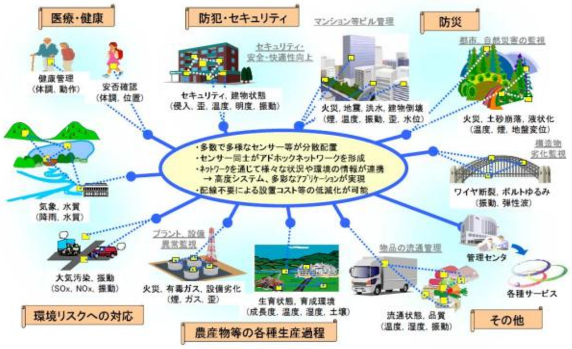
Outline

1. Introduction
2. Mobile Ad Hoc Networks
3. Controlled Mobility
4. Sensor Coverage
5. Network-Based Control
6. Conclusions and Future Works

Introduction

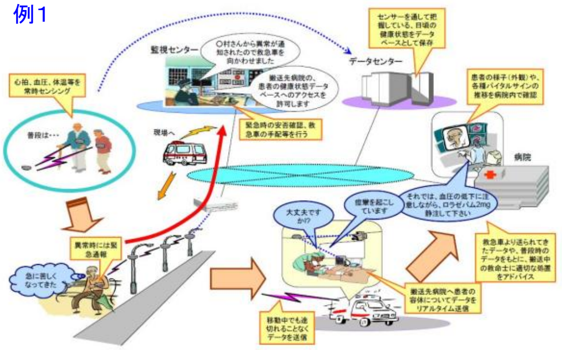


・多数で多様なセンサー等が分散配置
・センサー同士がアドホックネットワークを形成
・ネットワークを通じて様々な状況や環境の情報が連携
　→ 高度システム、多彩なアプリケーションが実現
・配線不要による設置コスト等の低減化が可能

総務省　ユビキタスセンサネットワーク技術に関する調査研究会報告書（平成16年7月）

Introduction

例１



総務省　ユビキタスセンサネットワーク技術に関する調査研究会報告書（平成16年7月）

Introduction

例２

Mobile Ad Hoc Networks

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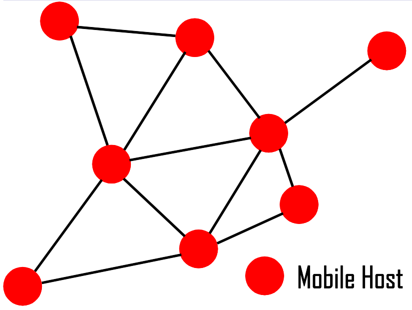
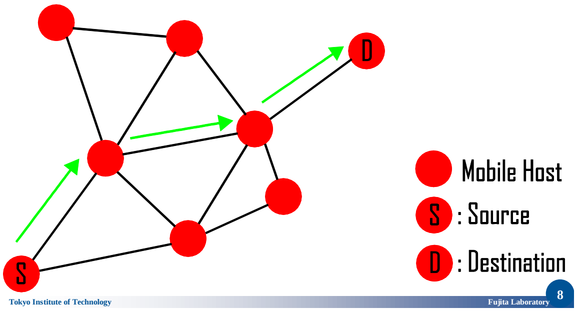
Mobile Ad Hoc Networks

Mobile Ad Hoc Networks:
The Wireless Networks constructed by only Mobile Hosts



Routing

Routing: Selecting the optimal route from the source to the destination.



Routing

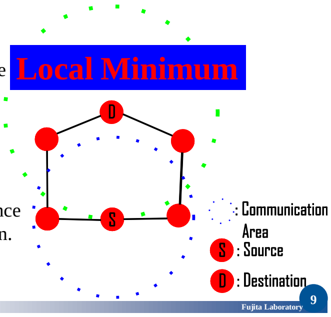
Routing with Location Information

I. Stojmenovic, 2002.

- **Greedy Routing**

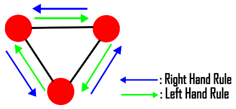
A node selects neighboring node that is closest to the destination among its neighbors.

A node sometimes fails to advance a message toward the destination.



Routing

- **Face Routing**



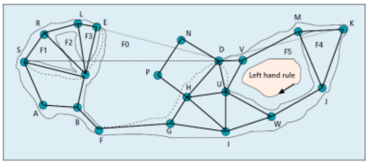
Route from S to D:
SCRLCELRSABFGIWJKMVD

- **Greedy-Face-Greedy Routing**

Greedy Routing ⟷ Face Routing

Switch

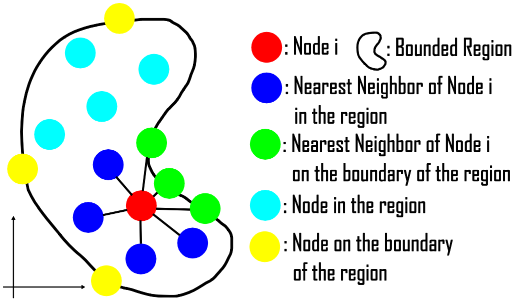
Route from S to D:
SCE-ECBF-FGHD



Routing

Routing without Location Information

A. Jadbabaie, 2004.



Routing

$$\begin{bmatrix} x_i(k+1) \\ y_i(k+1) \end{bmatrix} = \begin{bmatrix} x_i(k) \\ y_i(k) \end{bmatrix} \qquad i = 1, 2, \ldots, m$$

$$\begin{bmatrix} x_i(k+1) \\ y_i(k+1) \end{bmatrix} = \begin{bmatrix} \frac{\sum_{j \in N_i} x_j(k)}{d_i} \\ \frac{\sum_{j \in N_i} y_j(k)}{d_i} \end{bmatrix} \qquad i = m+1, m+2, \ldots, n$$

$\mathcal{N}_i$: The Set of Neighbors of the i th Node d_i : Cardinality of that Set
$(x_i(k), y_i(k))$: Coordinate of the i th Node at the time k

The first m nodes are at the boundary and have fixed known coordinates.
The remaining $n - m$ nodes are in the interior of the region whose virtual coordinates change in accordance of the above iteration.

The above equation is written as

$$x_{int}(k+1) = (D+B)^{1} A x_{int}(k) + (D+B)^{1} [b_1 b_2 \ldots b_m] x_p$$

$$y_{int}(k+1) = (D+B)^{-1} A y_{int}(k) + (D+B)^{-1} [b_1 b_2 \ldots b_m] y_p ,$$

where $x = [x_p \; x_{int}]^T$.

Routing

Theorem

In steady state, the virtual coordinates converge to points in the convex hull of the boundary nodes. Moreover, the coefficients of the virtual coordinates can be explicitly calculated as

$$\bar{\boldsymbol{x}} = \lim_{k \to \infty} \boldsymbol{x}_{int}(\boldsymbol{k}) = (\boldsymbol{D} + \boldsymbol{B} - \boldsymbol{A})^{-1}[\boldsymbol{b}_1, \boldsymbol{b}_2, \ldots, \boldsymbol{b}_m]\boldsymbol{x}_p$$

$$\bar{\boldsymbol{y}} = \lim_{k \to \infty} \boldsymbol{y}_{int}(\boldsymbol{k}) = (\boldsymbol{D} + \boldsymbol{B} - \boldsymbol{A})^{-1}[\boldsymbol{b}_1, \boldsymbol{b}_2, \ldots, \boldsymbol{b}_m]\boldsymbol{y}_p \, .$$

The key facts to prove the above theorem are as follows.

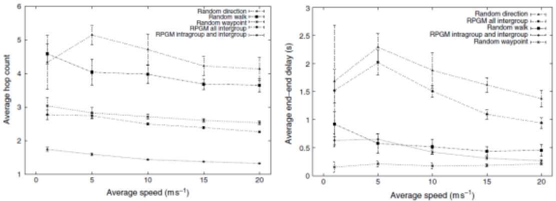
- $\boldsymbol{\rho}((\boldsymbol{D} + \boldsymbol{B})^{-1}\boldsymbol{A}) < \mathbf{1}$
- $\sum_{i=0}^{\infty}[(\boldsymbol{D} + \boldsymbol{B})^{-1}\boldsymbol{A}]^{i}(\boldsymbol{D} + \boldsymbol{B})^{-1} = (\boldsymbol{D} + \boldsymbol{B} - \boldsymbol{A})^{-1}$

Mobile Ad Hoc Networks

Mobility Models for Ad Hoc Networks

T. Camp *et al.*, 2002.

The performance of a routing protocol can vary significantly with different mobility models.

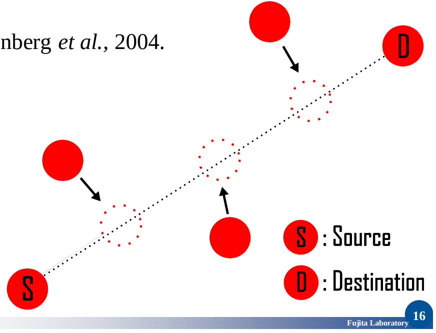


Outline

Topology Control

Mobility Control to Reach Optimality:
the Synchronous or Asynchronous Scheme

David K. Goldenberg *et al.*, 2004.



Topology Control

Objectives

- Power Efficiency

  e.g. Cost of Transmission, Cost of Mobility.
- Robustness of Communications

  e.g. Network Size, Irregular Paths.

The proposed algorithms guarantee these properties.

- Connectivity
- Convergence

Topology Control

Synchronous Mobility-Control Algorithm

- $\boldsymbol{x}_i$: current position of node i.
- $\boldsymbol{x}_{i-1}$ and $\boldsymbol{x}_{i+1}$: positions of nodes $i-1$ and $i+1$.
- $\boldsymbol{x}'_i$: updated position of node i.
- $g \in (0, 1]$: damping factor.
- L and R : internal boolean state variables.
- $\boldsymbol{moving}_i$: message signaling node i starting to move.

```
repeat
    send $x_i$ to neighbors $i-1$ and $i+1$
    receive $x_{i-1}$ and $x_{i+1}$
    move toward $x'_i = x_i + g\left[\frac{x_{i-1}+x_{i+1}}{2} - x_i\right]$
until (convergence)
```

Topology Control

Asynchronous Mobility-Control Algorithm

```
repeat
    send $\boldsymbol{x}_i$ to neighbors $i-1$ and $i+1$
    repeat listen() until $(L \wedge R == True)$
    send $\boldsymbol{moving}_i$ to neighbors $i-1$ and $i+1$
    set $L := False,\ R := False$
    move toward $\boldsymbol{x}_i' = \boldsymbol{x}_i + \boldsymbol{g}\left[\frac{x_{i-1}+x_{i+1}}{2} - \boldsymbol{x}_i\right]$
    repeat listen() until (arrive in bounded delay)
until (convergence)
subroutine listen():
        upon receive $\boldsymbol{x}_{i-1}$ do $L := True$
        upon receive $\boldsymbol{x}_{i+1}$ do $R := True$
        upon receive $\boldsymbol{moving}_{i\ 1}$ do $L := False$
        upon receive $\boldsymbol{moving}_{i\ 1}$ do $R := False$
```

Topology Control

Simulation Results of Power Efficiency

Cost of Transmission: $\boldsymbol{P(d) = a + bd^{\alpha}}$

Cost of Mobility: $\boldsymbol{P_m(d) = kd}$

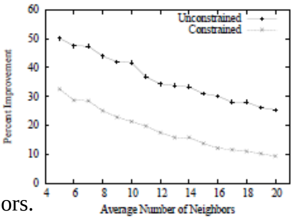
$a,\ b,\ k$: Constant $\alpha \in [2, 6]$ d : Distance

e.g.

$\boldsymbol{a = 10^{-7}}$ $\boldsymbol{b = 10^{-9}}$

$\alpha = 3$ $k = 0.1$

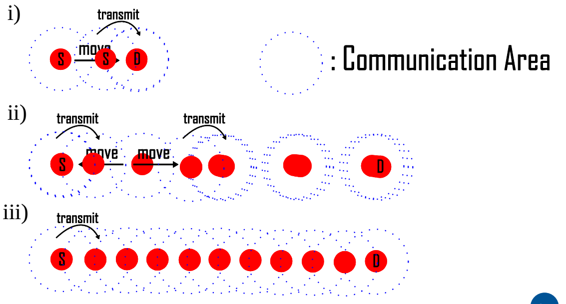
The constraint is that a communicating node does not move beyond the maximum communication range away from any of its non-communicating neighbors.



Multi-Robot Sensor Networks

WISER/s

R. Suzuki *et al.*, 2006.



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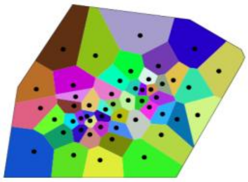
Sensor Coverage

Voronoi Partition

Given $\boldsymbol{S} \subset \mathbb{R}^2$ and a set $\mathcal{P} = \{\boldsymbol{p}_1, \boldsymbol{p}_2, \ldots, \boldsymbol{p}_n\} \subset \boldsymbol{S}$ of n distinct points, the Voronoi partition of S generated by $\mathcal{P}$ is the collection of sets $\{V_1(\mathcal{P}), V_2(\mathcal{P}) \ldots, V_n(\mathcal{P})\}$ defined by

$$V_i(\mathcal{P}) = \{q \in S \mid \|q - p_i\| \leq \|q - p_j\|,\ {}^{\forall}p_j \in \mathcal{P}\}.$$



S. Martinez *et al.*, 2007.

Sensor Coverage

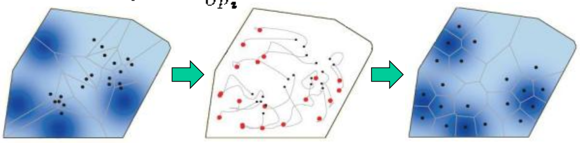
Distortion Problem

$f(\|q - p_i\|)$: Performance Function $\phi(q)$: Density Function

$H(\mathcal{P})$: Distortion Function

$$H(\mathcal{P}) = \sum_{i=1}^{n} \int_{V_i(\mathcal{P})} f(\|q - p_i\|)\phi(q)\,dq$$

$$u_i = -\frac{\partial H}{\partial p_i}$$



S. Martinez *et al.*, 2007.

Sensor Coverage

Mobile Sensor Network Deployment using Potential Fields

U: Scalar Potential Field F: Force x : Position of the Node

$\boldsymbol{x}_i$: Position of the other Node or Obstacle $\boldsymbol{r}_i = |\boldsymbol{x}_i - \boldsymbol{x}|$

k: Coefficient m: Mass ν: Viscosity Coefficient

$$\boldsymbol{U} = \boldsymbol{k}\sum_i \frac{\mathbf{1}}{\boldsymbol{r}_i} \qquad F = -\nabla U \qquad m\ddot{x} + \nu\dot{x} = F$$

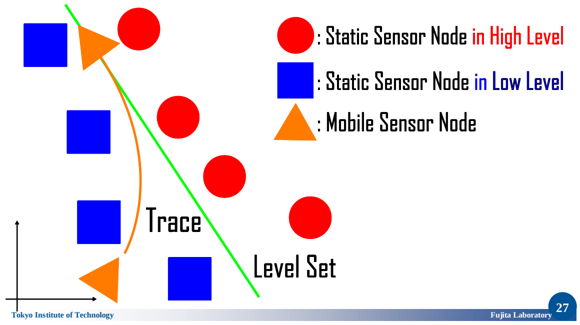
A. Howard *et al.*, 2002.

Outline

Network-Based Control

Level Set of Scalar Field

K. Dantu and G. S. Sukhatme, 2007.



● : Static Sensor Node in High Level

■ : Static Sensor Node in Low Level

▲ : Mobile Sensor Node

Network-Based Control

Control Law

$$\dot{\boldsymbol{x}} = \boldsymbol{\alpha Null}\left(\nabla \boldsymbol{G}(\boldsymbol{x})\right) + \boldsymbol{\beta}\nabla\boldsymbol{G}(\boldsymbol{x})^{\dagger}$$

$$\nabla\boldsymbol{G}(\boldsymbol{x}) = \nabla\boldsymbol{d}_1(\boldsymbol{x}) - \nabla\boldsymbol{d}_2(\boldsymbol{x})$$

$G(x) =$ (sensor reading at the mobile node) $-$ (threshold reading defining the contour to be traced)

α, β : Scalar Gains $Null\left(\nabla G(x)\right)$: Null Space of $\nabla\boldsymbol{G}(\boldsymbol{x})$

$\nabla\boldsymbol{G}(\boldsymbol{x})^{\dagger}$: Penrose Pseudoinverse of $\nabla\boldsymbol{G}(\boldsymbol{x})$

$\nabla\boldsymbol{d}_1(\boldsymbol{x})$: Direction of the Node with the Highest Gain Increase Ratio.

$\nabla\boldsymbol{d}_2(\boldsymbol{x})$: Direction of the Node with the Highest Gain Decrease Ratio.

Network-Based Control

Algorithm for the Mobile Sensor Node

```
loop
    for $i \in$ {Current neighbor list of mobile node} do
        $loc[i] \leftarrow$ Location of $i$
        $sense[i] \leftarrow$ Sensor reading of $i$
    end for
    $n1 \leftarrow$ Node with best gain increase gradient {using $loc[]$ and $sense[]$ }
    $n2 \leftarrow$ Node with best gain decrease gradient {using $loc[]$ and $sense[]$ }
    Compute $\nabla\boldsymbol{d}_1(\boldsymbol{x})$ and $\nabla\boldsymbol{d}_2(\boldsymbol{x})$
    Compute $\nabla G(x)$ and $G(x)$
    Compute $\dot{x}$
    Command $\dot{x}$ to actuators
end loop
```

Network-Based Control

● : Static Sensor Node in High Level

■ : Static Sensor Node in Low Level

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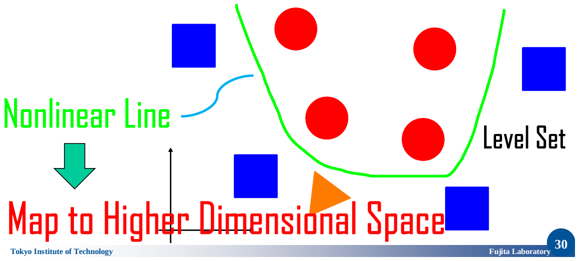
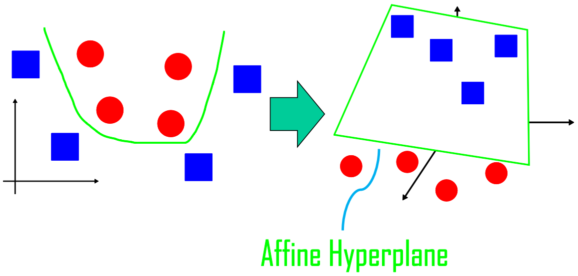


Map to Higher Dimensional Space

Support Vector Machine



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Conclusions and Future Works

Conclusions

I surveyed Sensor Networks.

Future Works

- Controlled Mobility
  - Balancing the Power Usage of each Node.
- Network-Based Control
  - Specifying the Problem.
  - Studying Support Vector Machine.