Particle Swarm Models for Swarm-based Network Sensor Systems

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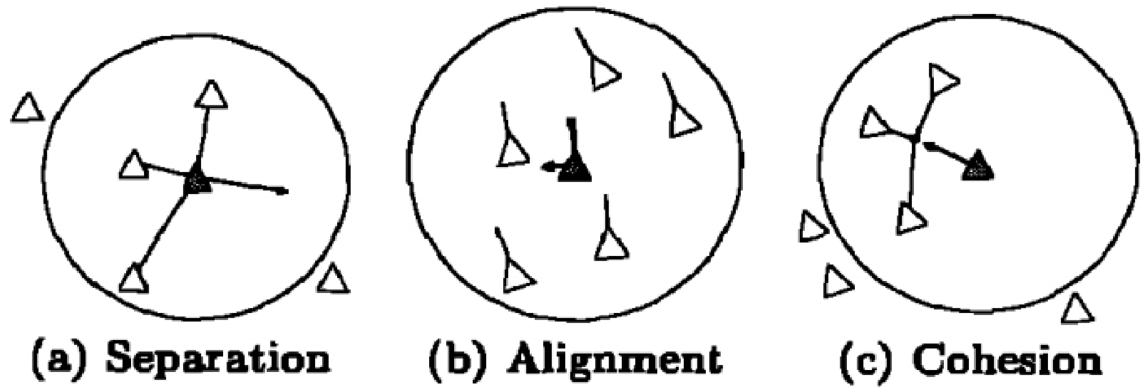
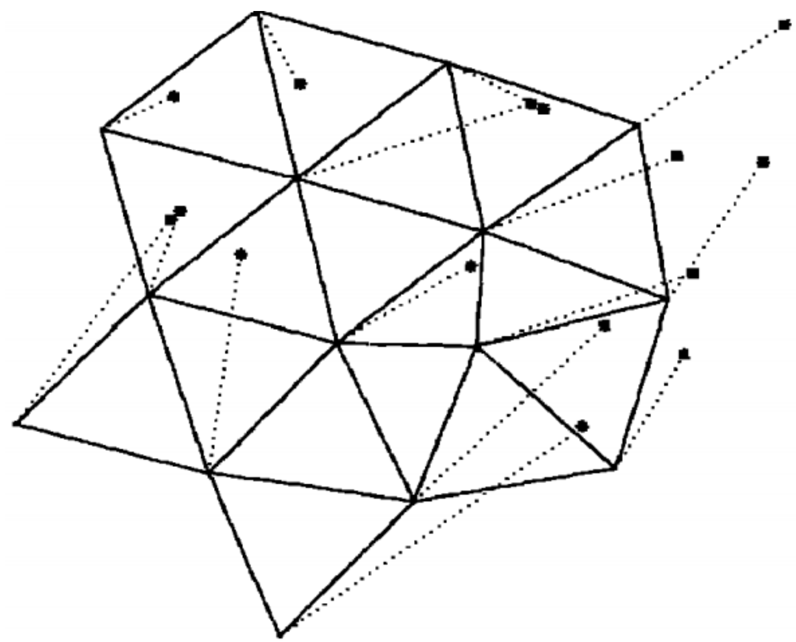
Network Applications

- Avalanche Victims
  - Sandia National Laboratories
- Miniature Sensor Systems
  - Passive Communications
  - Self-organization
  - Land Mines, Traffic Control, Exploration

Particle Swarm Basics

- Three Behaviors
  - Separation
  - Alignment
  - Cohesion
- Alignment Behavior
  - Minimum and Maximum Distances
  - Formation based on local interactions





The Algorithm

```
Loop ∀p_i ∈ P, i = 1, .., N
   Process boundaries
   Loop ∀p_j ∈ P_i, j = 1, ..., N_i
      Process neighbor p_j
      Calculate new direction
   end Loop
   Move in new direction
end Loop
```

Table 2: Swarm Algorithm Variables

Variable	Description
P	The set of mobile particles
N	The population size (mobile particles), $\|P\|$
p_i	The i^{th} particle in P
P_i	The set of particles in p_i's *neighborhood* (includes waypoints)
N_i	The number of particles in p_i's neighborhood, $\|P_i\|$
p_j	The j^{th} particle in P_i

Moving Particles

- A particle's target is selected:

$$v_{target} = F(boundary, P_i)$$

- For boundaries, the closest point is considered a particle:

$$\begin{aligned} v_{attract} &= p_b - p_i, b \in \{top, bottom, left, right\} & (3) \\ w &= -A\left(1 - \frac{d}{d_{max}}\right)^2 & (4) \\ v_{target} &= v_{target} + w v_{attract} & (5) \end{aligned}$$

Moving Particles (Cont.)

$$w_{periph} = B\left(\frac{1}{2}(\cos\theta + 1)\right)^2 \quad (6)$$

$$v_{attract} = p_j - p_i \quad (7)$$

$$v_{align} = \mathtt{direction}(p_j) \quad (8)$$

- For waypoints

$$w = C w_{periph} \left(\frac{d}{d_{max}}\right)^2 \left(-v_{align} \cdot \frac{v_{attract}}{d}\right) \quad (9)$$

- For particles

$$w = \begin{cases} w_{periph}\left(\frac{d-d_{min}}{d_{max}-d_{min}}\right)^2 & : \quad d \geq d_{min} \\ -D w_{periph}\left(1 - \frac{d}{d_{min}}\right)^2 & : \quad d < d_{min} \end{cases} \quad (10)$$

Moving Particles (Cont.)

- The contribution per particle:

$$(v_{new})_j = E v_{align} + w v_{attract} \qquad (11)$$

- The new target for the current particle:

$$v_{target} = \sum_j (v_{new})_j \qquad (12)$$

- The particle's new position:

$$p'_i = p_i + \alpha_s s_{max} v_{new} \qquad (13)$$

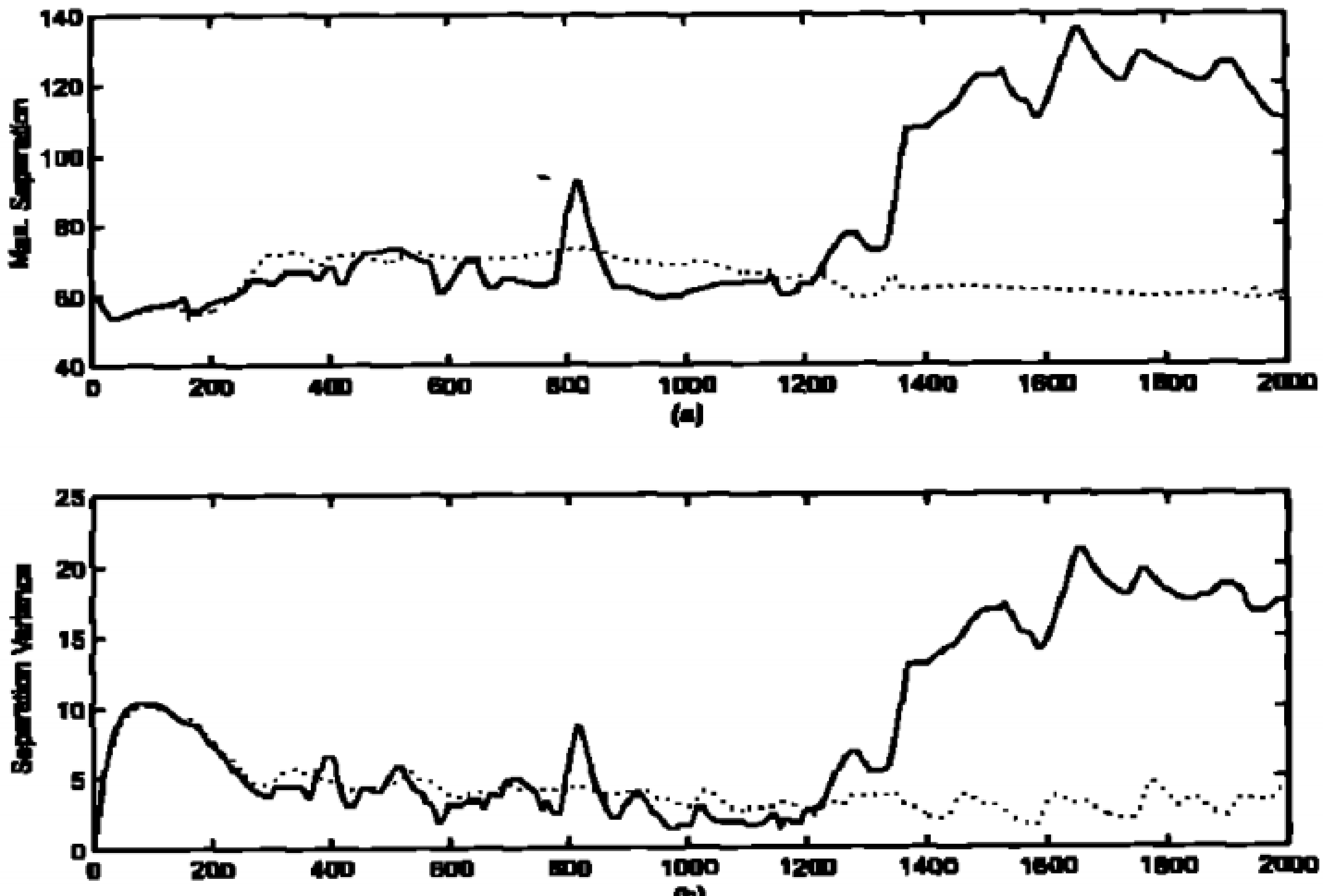
Tuning Constants

Table 3: Swarm Parameters

Parameter	Description
A	Boundary weight (Eq. 4)
B	Peripheral vision weight (Eq. 6)
C	Waypoint weight (Eq. 9)
D	Repulsion weight (Eq. 10)
E	Alignment weight (Eq. 11)
α_s	Speed factor (Eq. 13)
θ_{max}	Max turn angle (Fig. 6)
s_{max}	Max particle speed (Eq. 13)
d_{max}	Max sight distance

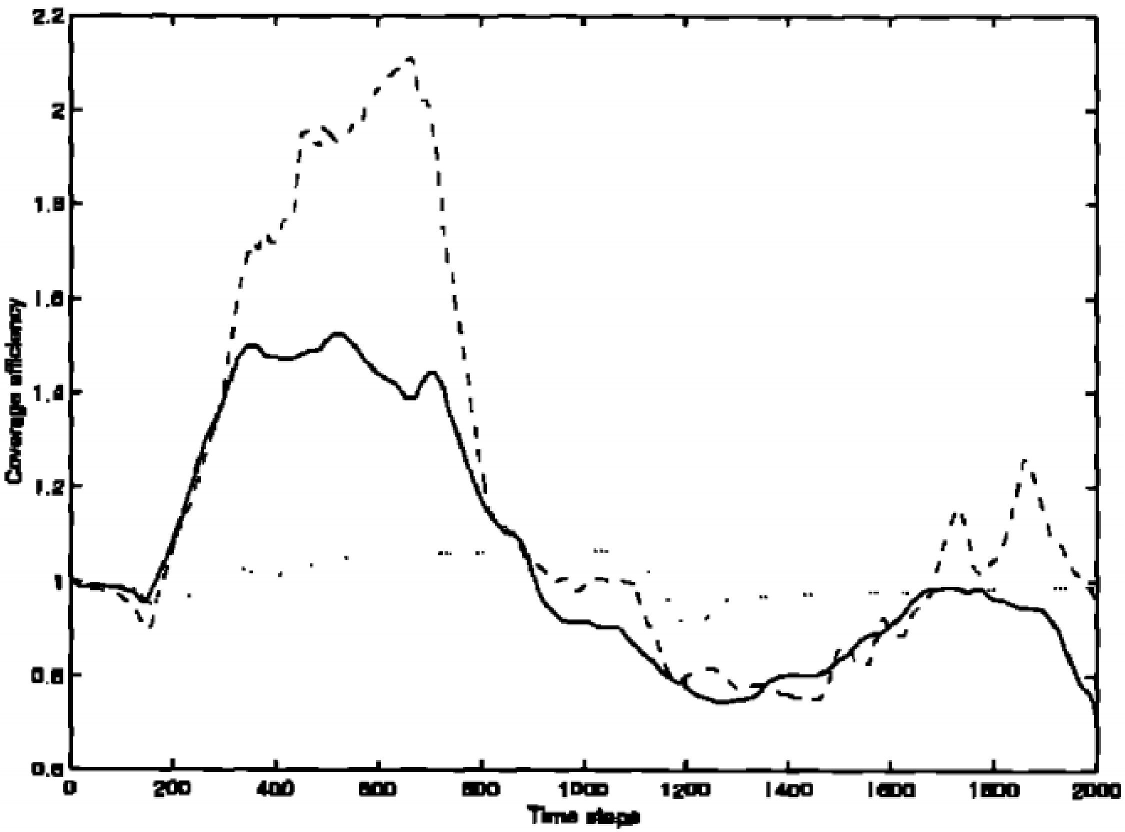
Varying Connectivity with E

- E = 0.05 (solid) vs E = 0.50 (dotted)



Varying Coverage Efficiency with E

- E = 0.50 unguided (light dotted) vs E = 0.05 guided (dotted) vs E = 1.0 guided (solid)



E	Unguided	Guided
0.05	0.1607	0.4487
0.10	0.0539	0.4342
0.25	0.0648	0.3317
0.50	0.0431	0.2847
1.00	0.0353	0.2571