Power-Aware Population Protocols

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Overview

1. Network model (Population protocols) and motivation
2. Energy model
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2. Energy model

3. Data collection in Population Protocols
   - Analytical results on energy complexity for a known time optimal protocol and a new power-aware protocol
   - Lower bounds on energy complexity
Population Protocols (PP) [Angluin et al, PODC ’04]:

1. Finite state agents (sensors): Anonymous, uniformly bounded memory
2. Interaction in pairs:

\[ p \xleftrightarrow{} q \rightarrow p' \xleftrightarrow{} q' \]

3. Time: the number of interactions
Population Protocols (PP) [Angluin et al, PODC ’04]:

1. Finite state agents (sensors): Anonymous, uniformly bounded memory
2. Interaction in pairs:
3. Time: the number of interactions

Examples of passively Mobile Sensor Network
- ZebraNet (wildlife tracking)
- EMMA (pollution monitoring)
Cover Time Property in PP [Beauquier et al, PODC ’10]:

**Definition of cover time \( (cv_i) \)**

In any \( cv_i \) consecutive interactions, an agent \( i \) meets every other agent at least once.
Cover Time Property in PP [Beauquier et al, PODC ’10]:

**Definition of cover time ($c_{vi}$)**

In any $c_{vi}$ consecutive interactions, an agent $i$ meets every other agent at least once.

$c_{Vi} < c_{Vj}$

Fastest agent:

$c_{v_{min}} = \min\{c_{vi}\}$

Worst case complexity

Faster  Slower
Sleep

\[ E_{slp} \]
Energy Model

\[ E_{\text{wkp}} = E_{\text{slp}} + E_{\text{sw}} + E_{\text{trans}} \]
Energy Model

$E_{wkp} = E_{slp} + E_{sw} + E_{trans}$
Energy Model

\[ E_{\text{wkp}} = E_{\text{slp}} + E_{\text{sw}} + E_{\text{trans}} \]

Sleep  Terminated

Power-Aware Population Protocols
Energy complexity measure

$E_{s_{\text{max}}}$: The maximum energy spent by an agent in the worst case
Data Collection

- Time optimal protocol [Beauquier et al, PODC'10]
- Power-aware protocol

**Power-Aware Population Protocols**

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Data Collection

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- Power-aware protocol
If $cv_i < cv_j \land mark_i := 1$
Protocol I: TTFM [Beauquier et al, PODC’10]

If \( cv_i < cv_j \land mark_i := 1 \)

Theorem

An upper bound on the maximum energy spent by an agent is

\[
(2cv_{\min}\left\lceil \frac{|NF|}{M \times |F|} \right\rceil - 1)E_{wkp},
\]

where \( M \) is the size of memory, \( F \) is the set of fastest agents, and \( NF \) is the set of non-fastest agents.
$mark_i := 1$
Power-Aware Protocol II: Energy-Balanced TTFM(\(\lambda\))

\[ P_i = E_0 \]

\[ E_0 \lambda : E_0 \lambda \]

TTFM

i:

j:
Power-Aware Protocol II: Energy-Balanced TTFM($\lambda$)

$i$: $\frac{E_0}{\lambda}$

$j$: 

$E_0^\lambda$
Power-Aware Protocol II: Energy-Balanced TTFM(\(\lambda\))

\[ E_0 : \frac{E_0}{\lambda} : j \]

\[ i \rightarrow j \]
Power-Aware Protocol II: Energy-Balanced TTFM(\(\lambda\))

Parameter: \(\lambda \in (0, 1]\)

1. \(\frac{E_0}{\lambda}\) is too small: \(EB-TTFM = TTFM\)
2. \(\frac{E_0}{\lambda}\) is too large: Values are transferred to slowest agents
Power-Aware Protocol II: Energy-Balanced TTFM(\(\lambda\))

\[ i := 1 \]

\[ E_0 : \]

When \( \left( \frac{\theta}{1-(1-\theta)\lceil \frac{|F|}{2} \rceil} \right)cv_{min}E_{wkp} \leq \frac{\lambda-1}{\lambda} E_0 \leq (2cv_{min} - 1)E_{wkp}, \]

**Theorem**

*An upper bound on the maximum energy spent by an agent is*

\[
\frac{\lambda-1}{\lambda} E_0 + (1 + \frac{1}{2-\theta})cv_{min}E_{wkp} = \Theta(cv_{min}E_{wkp})
\]

\( \theta = \frac{E_{slp}}{E_{wkp}}, \ |F|: \) number of fastest agents, \( cv_{min}: \) smallest cover time
\[ \tilde{\lambda} = \frac{E_0}{(E_0 - \left(\frac{\theta}{1 - (1 - \theta) \lceil |F| / 2 \rceil}\right)c_{\text{min}}E_{wkp})} \]

\[ E_{\text{max}}(EB-TTFM(\tilde{\lambda})) = (1 + \frac{\theta}{1 - (1 - \theta) \lceil |F| / 2 \rceil} + \frac{1}{2 - \theta})c_{\text{min}}E_{wkp} \]

\[ E_{\text{max}}(TTFM) = (2c_{\text{min}} - 1)E_{wkp} \]

(\( \theta = \frac{E_{\text{slp}}}{E_{wkp}} \), \( c_{\text{min}} \): smallest cover time, \( |F| \): number of fastest agents)
Comparison of energy performances

For $|F| \geq 10$ and $\theta \leq (3 - \sqrt{5})/2 \approx 0.38$, $EB\text{-}TTFM(\tilde{\lambda})$ outperforms $TTFM$. ($\theta = \frac{E_{slp}}{E_{wkp}}$, $|F|$: the number of fastest agents)
Lower Bound on energy complexity in population protocols

**Theorem**

The energy spent by an agent in the worst case is at least
\[ \max\left\{ \frac{E_{s_{\text{max}}}(TTFM)}{\left\lceil \frac{|F|}{2} \right\rceil}, cv_{\text{min}}E_{\text{wkp}} \right\}. \]

**Corollary**

When \(|F| \leq 2\), TTFM is energy-optimal.

**Corollary**

EB-TTFM(\(\tilde{\lambda}\)) reaches the lower bound asymptotically.
Thanks for your attention!