Theoretical Analysis of Redundant Movements in Collections of Autonomous Mobile Programs

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Talk Outline

Autonomous Mobile Programs (AMPs)

- AMPs are mobile agents
  - aware of their resource needs
  - sensitive to the execution environment
  - periodically seek a better location
- $$T_h > T_n + T_{comm} \quad (1)$$
  Time on the current location > *Min time on fastest network location* + *Time to transfer*
- Been investigated using
  - Mobile languages (e.g. *Java Voyager* [DMT10])
  - *Simulation* [CKPT09]

Greedy Effects

- are redundant movements:
  - locally optimal choice, but
  - globally non-optimal choice
- occur when AMPs rebalance after a termination or new AMPs start
- are observed in other distributed systems

Location Thrashing

Due to lack of information about other AMPs intending to move to the same location

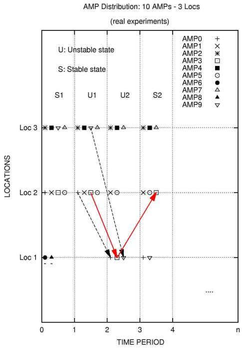

Figure: Redundant rebalancing

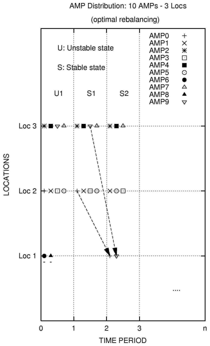

Figure: Optimal rebalancing

Location Blindness

Due to lack of information about the remaining execution time of other AMPs

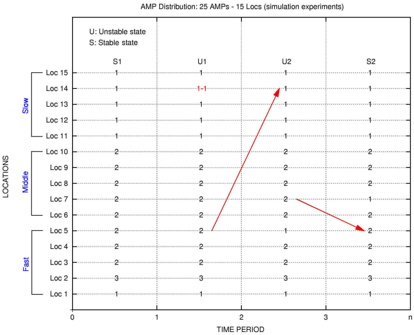

Figure: Redundant rebalancing

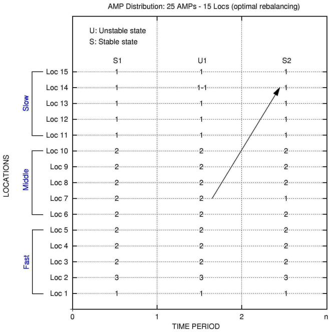

Figure: Optimal rebalancing

Negotiating AMPs

- Reduce greedy effects by sharing information
- Methods of AMP negotiation: Malicious/Honest: queuing, competitive, probabilistic, relationship, etc.
- cNAMPs are negotiating AMPs with a competitive scheme:
  - announce their intentions to move
  - compete with each other for faster locations
- cNAMPs eliminate location thrashing

Networks & Locations

Types of Networks

- Homogeneous network: all locations have the same CPU speed, except the initiating location
- Heterogeneous network: locations have different CPU speeds
  - Subnetwork is a set of locations with identical CPU speeds

Types of Locations

- Root location where all cNAMPs start
- Heavy location has optimal number of cNAMPs
- Light location has one cNAMP less than heavy location

Balanced States

In a balanced state no cNAMP can gain a greater relative speed by moving

- In optimal balance locations with the same CPU speed have equal number of cNAMPs
- In near-optimal balance
  - locations of one subnetwork have different number of cNAMP
  - the discrepancy is at most one cNAMP

Proof Cases

1. where a cNAMP terminates
2. where the cNAMP that first discovers the termination is

i.e. from (1) whether
$$\frac{W_r}{R_h} > \frac{W_r}{R_n} + T_{comm} \qquad (2)$$

- W_r - remaining work
- R_h - cNAMP relative speed on the current location
- R_n - cNAMP relative speed on the new location

Analysed Networks

- Homogeneous network
  - Optimally balanced
  - Near-optimally balanced
- Heterogeneous network
  - Optimally balanced
  - Near-optimally balanced

Homogeneous Network Theorems

Proved by case analysis [CKT10]

- Optimal balance
  - No rebalancing when a cNAMP terminates from a non-root location (3)
  - No greedy effect
- Near-optimal balance
  - No rebalancing when a cNAMP terminates from a heavy location (4)
  - At most one redundant movement (5)

Homogeneous Network Probability Analysis

- $$P_1 = P_{termR} \cdot P_l \quad (8)$$
  - P_1 – greedy effect probability
  - P_{termR} – cNAMP terminates from the root location
  - P_l – cNAMP from a light location discovers the information first
- less than 10% probability in a network of more than 10 locations

Heterogeneous Networks with q subnetworks

Proved by case analysis

- Optimal balance
  - At most $q-2$ redundant movements (7)
- Near-optimal balance
  - At most $q-1$ redundant movements (6)

Heterogeneous Network Probability Analysis

- $$P_2 = P_{termRh} \cdot P_{des} \tag{9}$$
  - P_2 – probability of $q - 1$ redundant movements
  - P_{termRh} – cNAMP terminates from a location with the highest relative speed
  - P_{des} – cNAMPs discover the information in the descending order of cNAMP relative speeds
- Probability median value of $q - 2$ redundant movements does not exceed 1%

Conclusion & Future Work

We have

- Identified two types of the greedy effects
- Introduced negotiating AMPs (cNAMPs) to eliminate location thrashing
- Used case analysis to prove absolute bounds on greedy effect (3)–(7)
- Used statistical analysis to prove median probability of redundant movements
- Proved properties about collections of cNAMPs, e.g. the maximum number of redundant movements that may occur

Future Work

- Investigation of cNAMP behaviour on wide area networks.

Questions?

Termination at a Non-root Location

After a cNAMP termination from optimally balanced homogeneous network, the system has $\left[\left[\frac{f(2k+1)-1}{2(f+1)}\right]\right]$ cNAMPs on the root location, $\left[\left[\frac{2k-3f-1}{2(f+1)}\right]\right]$ cNAMPs on a non-root location, and $\left[\left[\frac{2k-f+1}{2(f+1)}\right]\right]$ cNAMPs on the remaining non-root locations.

Now we analyse possible movements which may occur from the root location to the light location.

First, we calculate cNAMP execution time on the root location before a cNAMP movement:

$$T_h = \frac{W_r}{S} \cdot \left[\left[\frac{f(2k+1)-1}{2(f+1)}\right]\right]. \quad (1)$$

The light location becomes heavy location after a cNAMP arrival, and has $\left[\left[\frac{2k-f+1}{2(f+1)}\right]\right]$ cNAMPs. The execution time is

$$T_n = \frac{W_r}{S} \cdot \left[\left[\frac{2k-f+1}{2(f+1)}\right]\right]. \quad (2)$$

Condition of a cNAMP movement is

$$\frac{W_r}{S} \cdot \left(\left[\left[\frac{2kf+f-1}{2(f+1)}\right]\right] - \left[\left[\frac{2k-f+1}{2(f+1)}\right]\right]\right) > T_{comm}. \quad (3)$$

To satisfy (3) at least $\left[\left[\frac{2kf+f-1}{2(f+1)}\right]\right] - \left[\left[\frac{2k-f+1}{2(f+1)}\right]\right]$ must be positive. However, $2kf < 2k$ and $f-1 < 1-f$, which means that $\left[\left[\frac{2kf+f-1}{2(f+1)}\right]\right] - \left[\left[\frac{2k-f+1}{2(f+1)}\right]\right] \leqslant 0$. Thus, cNAMPs from the root location never move to a non-root location in a near-optimal balanced state.

Probability of the Redundant Movement in Homogeneous Networks (1)

Greedy effect probability in a homogeneous network is a product of the probability of a cNAMP termination from the root location and the probability of a discovery a better opportunity for execution first by a cNAMP from a light location:

$$P = P_{termR} \cdot P_l. \tag{4}$$

To calculate the probability of a cNAMP termination at the root location, assume that cNAMP execution time on locations follows a Poisson distribution. The mean cNAMP execution time on the root, heavy and light locations is given by:

$$T_{loc} = \frac{W \cdot x_{loc}}{S_{loc}} = \frac{W}{R_{loc}},$$

Hence, the rate of cNAMP terminations at the root, heavy and light locations is:

$$\nu_{loc} = \frac{R_{loc}}{W},$$

Assume, that there are N_l light locations and N_h heavy locations in the system. Then probability that a cNAMP terminates at the root location is

$$P_{termR} = \frac{\nu_{root}}{\nu_{root} + \nu_h + \nu_l}$$

or

$$P_{termR} = \frac{R_{root}}{R_{root} + N_h R_h + N_l R_l}. \tag{5}$$

Probability of the Redundant Movement in Homogeneous Networks (2)

cNAMPs from non-root locations have an equal probability of discovering a better opportunity for execution first. The total number of cNAMPs on non-root locations is

$$x_{nonroot} = N_h x_h + N_l x_l. \quad (6)$$

The probability that a cNAMP from a light location discovers better opportunity for execution is the ratio of the total number of cNAMPs on light locations to the total number of cNAMPs on non-root locations:

$$P_l = \frac{N_l x_l}{N_l x_l + N_h x_h}. \quad (7)$$

Thus, substituting (5) and (7) in (4), we get the following probability of the greedy effect after a cNAMP termination from a near-optimally balanced homogeneous network:

$$P = \frac{R_{root}}{R_{root} + N_h R_h + N_l R_l} \cdot \frac{N_l x_l}{N_l x_l + N_h x_h}. \quad (8)$$

To investigate the range of values that P can take, we calculate P, changing the total number of locations from 3 to 50, the number of light locations from 1 to $N - 2$, the load factor, $0.45 < f < 0.55$, and the number of cNAMPs. In the calculation we consider only cases when $N_h \cdot N_l \neq 0$, because a system must have both heavy and light locations in order that the greedy effect can occur. The root and light locations must have at least one cNAMP.

Natalia Chechina, Peter King, Rob Pooley, and Phil Trinder.
Simulating autonomous mobile programs on networks.
In *PGNet '09*, pages 201–206, Liverpool, UK, 2009.

Natalia Chechina, Peter King, and Phil Trinder.
Complete experimental and theoretical analysis of greedy effects in autonomous mobility.
Tech.Rep. 0073, H-W University, Edinburgh, UK, 2010.
http://macs.ac.uk/∼nc75/publications/0073.pdf

X. Y. Deng, G. J. Michaelson, and P. W. Trinder.
Cost-driven autonomous mobility.
Comput. Lang. Syst. and Struct., 36(1):34–59, 2010.