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Tarantula Mating Based Multi-Agent Routing Strategy for Manufacturing Problems

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Abstract—*A very interesting behavior as observed by author for Tarantula spider is that the female spider sometimes eats the male spider just after their mating in order to immediate need for food. This strange behavior has been used to propose a multi-agent and multi-criteria fuzzy routing strategy to be applied in manufacturing situations. A hierarchical structure of agents has been considered where the worker agents at the leaf level calculate shortest paths, congestion in a path, number of intermediate nodes and identify deadlock condition in the network. A master agent at the top of the hierarchy controls them. Fuzzy theory concepts have been used in case of shortest path calculation and in the calculations for PROMETHEE multi-criteria decision analysis. A network instance has used in order to implement the strategy as proposed in this research study.*

Keywords: *Tarantula Mating Behavior, Multi-Agent Based Strategy, PROMETHEE, Routing Strategy, Fuzzy Theory*

1. INTRODUCTION

This paper is based on the view that in dynamic environments, it is very difficult to decide over the entire optimum path before the journey begins, since, the data, such as, the congestion data, deadlock data, shortest path data may change over time. Thus by the time, when a particular job reaches a particular node, there is a chance that the previously determined optimum path may not be optimum anymore. Thus, instead of finding the entire point-to-point optimum path, it may be better to choose the next best node to route a job towards the destination. Thus, instead of finding the entire point-to-point optimum path, it may be better to choose the next best node to route a job towards the destination. Agent technology, Multi-criteria decision analysis with fuzzy orientation have been used to implement the routing strategy as proposed in this paper.

An agent is a computational system which is long lived, has goals, self-contained, autonomous, capable of independent decision making. The main characteristics of agents are autonomy, social ability, responsiveness, pro-activeness, adaptability, mobility, veracity, rationality. Among the benchmark multi-agent technologies, GAIA [1] is a hierarchical agent-based architecture using the concepts of object-oriented analysis and design. Wooldridge et al. [1] used some concepts from FUSION [2]. GAIA is suitable for the development of the systems like ADEPT [3], ARCHON [4]. In GAIA, every agent has a role to play and they interact with each other in a certain pre-defined way which is defined in their protocols. ROADMAP [5] is another agent-based methodology which is an extension of GAIA for complex open systems. Some of the other significant technologies include PROMETHEUS [6], TROPOS [7], PASSI [8], TAPAS [9] and so on. Some of the agent based technologies as applied in manufacturing include PROSA [10], ADACOR [11], HCBA [12] and so on.

The strategy as proposed in this paper has also used multi-criteria decision analysis technique. Multi-Criteria Decision Analysis (MCDA) techniques are basically methods to aid decision making for the cases where a decision depends on more than a single criterion. MCDA techniques can be categorized into 1) Value Measurement Models, such as, AHP (Analytic Hierarchy Process proposed by Saaty [13, 14], Simple Multi-Attribute Rating Technique (SMART) proposed by Edwards and Barron [15]; 2) Goal, Aspiration and Reference Level Models, such as, TOPSIS (Technique for Order Performance by Similarity to Ideal Solution); 3) Outranking Models, such as, ELECTRE I, II, III, IV [16-19], PROMETHEE [20-21], NAIADE [22-23]. The following section 2 describes the multi-agent strategy as proposed in this paper.

2. THE PROPOSED STRATEGY

This paper has used a hierarchical structure of agents (Fig. 1) and PROMETHEE multi-criteria outranking method with a fuzzy orientation. The leaf level of the hierarchy contains worker agents. Each of the worker agents performs a particular task. The worker agents considered in this research study are 1) shortest path agent, 2) congestion agent, 3) deadlock agent and 4) hops agent. The Master agent takes the final decision from top of the hierarchy. After performing the task, each of the worker agents is killed by the master agent after taking the result of the performed task from the worker agent. Thus, the hierarchical structure does not exist after all the tasks are performed by all the worker agents. The final decision is taken by the master agent based on PROMETHEE multi-criteria decision analysis technique based on the information provided by the worker agents. The master agent gets notification after killing each of the worker agents. The idea conveyed in this research study stems from the mating incident of a type of spider called Tarantula where the female spider eats the male one after mating. The analogy of such interesting mating behavior with the idea in this research study can be described in Fig. 2.

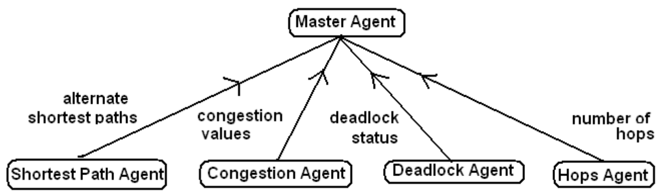


Fig. 1: Hierarchy of Agents

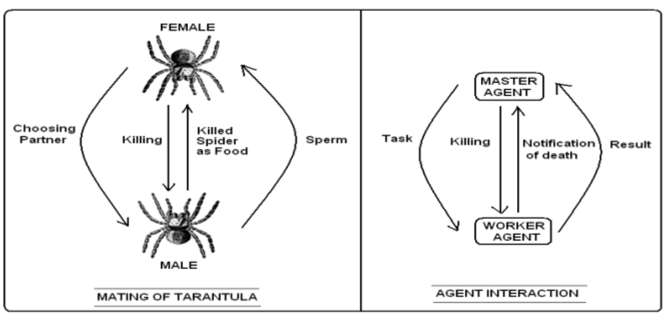


Fig. 2: Analogy with Tarantula Mating Behavior

The routing strategy considered in this research study finds the next optimum neighboring node through agent based technique, instead of finding the entire source-to-destination path. Thus the worker agents and then the master agent will start functioning whenever there will be a need to route a job to the next optimum neighboring node and whenever a new job enters the system. The master agent invokes and initiates the actions of the worker agents, just like the female spider chooses a male spider for mating. The worker agent, after performed their tasks, return the results to the master agent, just like the male spider transfers the genetic material to the female spider during mating. The master agent kills the worker agents after receiving the results from the worker agents, just like the female spider kills and eats the male spider after mating. The master agent gets the notification of the killing of the worker agents, just like the female spider takes the male spider as food. The various functions as performed by various worker agents and the master are described in the following subsections.

2.1 Shortest Path Agent

The shortest path agent finds the fuzzy shoretst path towards destination node from the each of the neighbors of the current node. The fuzzy shortest path is determined by the fuzzy Dijkstra's algorithm following the research study of Deng et al. [24]. The algorithm is depicted in the Fig. 3. Here, *perm[]* represents Permanent node; *v[]* holds the distance to each node from current node. In this algorithm, the edge lengths are triangular fuzzy numbers from which the fuzzified edge lengths are calculated from the fuzzy numbers by using expression (1) below.

$$v_{ij} = \frac{\Pr_{ij}}{\sum_{j=1}^{C} \Pr_{ij}} \tag{1}$$

Where, v_{ij} is the normalized value of the preference and an entry in the *i-th* row and *j-th* column in the matrix containing normalized values for the *i-th* decision maker and the *j-th* criterion; $\Pr_{ij}$ is the respective original preference value delivered by *i-th* decision maker, for the *j-th* criterion.

```
Input: Set of edges (E), Set of vertex (V), d[], source node (s), destination node (d)
Output: Shortest Path from s to d of length contained in v[d]

1.  Initialize:
    For each edge e ∈ E
      Set Fuzzy Number W_e = (a_e + 4*b_e + c_e) / 6
    End For
    Set d[s] ← 0 and d[i] ← ∞, ∀ i, i ≠ s
    Set permanent node p ← s
2.  For each neighbor j ∈ neighbor(p)
        Set v[j] ← minimum {d[j], d[p]+c_p,j}
        Set pred[j] ← p
    End For
3.  Find minimum among non-permanent node:
    Set min ← ∞
    For each vertex v ∈ V
        If v is not permanent node Then
            If d[v] < min Then
                Set min ← d[v]
                Set j' ← v
            End If
        End If
    End For
4.  Set next permanent node p ← j'
5.  Repeat steps 2 – 4 until all the nodes become permanent or the destination is
    reached.
```

Fig. 3: Fuzzy Dijkstra's Shortest Path Algorithm

```
For each neighbor i
        Record number of jobs on arc (src, i)
End For
For each neighbor i
        Find the nextnode n of i on SP(i)
        Record number of jobs on arc (i, n)
End For
```

Fig. 4: Congestion Finding Algorithm

```
For each neighbor n1
    For each neighbor n2
        If n1 != n2 Then
          If neighbor[n1] != neighbor[n2] Then
              Safe[n1] = 1
              Safe[n2] = 1
          End If
        End If
End For
```

Fig. 5: Deadlock Finding Algorithm

2.2 Congestion Agent

The congestion agent checks for the congestion of the edges from the current node to each of the neighboring nodes and from each of the neighboring nodes to their immediate neighbors on their shortest paths towards destination (Fig. 4). Although the congestion can be represented by more than one factor, but in this research study, congestion is represented by the number of jobs travelling on a particular edge.

2.3 Deadlock Agent

The deadlock agent (Fig. 5) checks whether the neighbors of the current node faces any immediate cyclic path. Let the current node is *c* and the neighbors of c are *x, y* and *z*. If the immediate neighbors of two or more neighbor of the neighbors *x, y, z* be same, then the algorithm marks those neighbors (*x* and/or *y* and/or *z*) as unsafe, otherwise they are safe. It can easily be realized that, in dynamic environment where the number of jobs on each path vary continuously, it will be less significant to find a cyclic deadlock throughout the entire network. Thus instead of finding the cyclic deadlock in the entire network, it will better to find such an immediate cycle. The algorithm endeavors to avoid cyclic path since in such path, there is more chance of facing a collision.

2.4 Hops Agent

The hops agent finds the number hops or intermediate nodes on a path towards destination (Fig. 6). Thus for each of the shortest path from the neighboring nodes towards destination, there is a particular number representing the number of intermediate nodes on the way. The target is to choose that particular neighbor as the better node which will have least number of hops since, the greater the number of hops, greater is the chance of facing more congestion, more deadlock, more blockage at the nodes due to loaded buffers.

2.5 Master Agent

The master agent takes the final decision based on the information provided by the worker agents (Fig. 7). The shortest path agent provides the alternate path through neighbor of the current node. Thus the number of alternate paths equals the number of immediate neighbors of the current node. The congestion agent provides the congestion data in terms of the number of jobs travelling on the edge between the current node and each of the neighboring nodes and the number of jobs travelling on the edge between the immediate neighbors of the current node and the neighbors of the immediate neighbors. The deadlock agent provides the boolean values indicating whether the immediate neighbors of the current node are safe. The hops agent delivers the number of hops or intermediate nodes between the current node and the destination node on each of the alternate paths through the neighbors. Based on the above data and information, the master agent takes decision using a multi-criteria decision analysis technique known as PROMETHEE by selecting best neigbor to which the job may be routed next.

```
For each neighbor i
    Find shortest path SP(i) to destination d from i
    Set count[i] ← 0
    For each node from n on SP(i)
        Set count[i] ← count[i] + 1
    End
End For
```

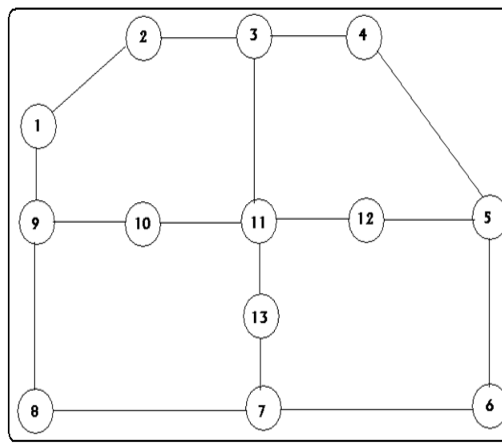
Fig. 6: Hops Finding Algorithm

```
1.  Input a network with fuzzy edge values
2.  Input source and destination nodes s and d respectively
3.  Find neighbor N of s
4.  For each neighbor n ∈ N
        Find shortest path p from n to d
        Store p in PATH
    End For
5.  For each neighbor n ∈ N
        Find path p ∈ PATH FROM N
        Find number of jobs on edge (s, n)
        Find number of jobs on edge (n, i), i: neighbor of n on p
        Check whether there is any deadlock cycle with n
        Calculate number of hops from n on p
    End For
6.  Apply PROMETHEE to find the best neighbor n
```

Fig. 7: Algorithm for Master Agent

3. RESULTS AND DISCUSSION

The multi-agent and multi-criteria approach as proposed in this research study has been applied on a network example (Fig. 8). The experimentation has been performed in C# of Visual Studio .Net 2008 in a dual core PC with 2 GB memory. The worker agents have been implemented by using threads which run in parallel through thread synchronization. The relevant details are shown in Fig. 9. Next, a total of 4 decision makers is assumed and they all assign their own preference to the sever criteria. The seven criteria are – 1) Path length, 2) Number of jobs travelling on the edge from current node (node 2) to immediate neighbors (nodes 1, 3). The respective edges in this example are: 2-1 and 2-3, 3) Number of jobs travelling on the edge between the immediate neighbors (nodes 1, 3) and their neighbors on their respective shortest paths. Deadlock status of each of the neighbors, 5) Number of intermediate nodes or hops.



ARC	COST
1 – 2	(1,4,9)
1 – 9	(2,10,12)
2 – 3	(3,8,10)
3 – 4	(1,3,6)
3 – 11	(12,15,17)
4 – 5	(7,8,10)
5 – 6	(4,10,11)
5 – 12	(9,11,15)
6 – 7	(6,11,13)
7 – 8	(1,10,14)
7 - 13	(3,9,16)
8 – 9	(3,10,20)
9 – 10	(8,12,13)
10 – 11	(1,3,9)
11 – 12	(11,20,21)
11 – 13	(2,9,10)

Fig. 8: Network Diagram

Fig. 10 shows the preferences as provided by the 4 decision makers (DM), the fuzzy weights as calculated for the above five criteria. For calculating the fuzzy weights, first the preferences for each DM are converted to probability values. Thus there will be 4 probability values from each DM under each criterion. Then the minimum, intermediate and maximum values are found out from each of the 4-valued set for each criterion. These three calculated numbers form the fuzzy number for each criterion and then the fuzzified value of the criterion is calculated following expression (2) shown below.

Source Node: 2; Destination Node: 13

Number of Neighbours of Souce Node 2: 2 ⇨ 1, 3

Alternate paths through neighbors

Alternates	Paths
A1	2 –1 –9 – 10 – 11 – 13
A2	2 – 3 – 11 – 13

Congestion Weights

6	1	5	4 3
7	2	2	

Fig. 9: Relevant Data on Network

Preference for 5 Criteria from Four Decision Makers (DM)

DM	C1	C2	C3	C4	C5
1	2	4	1	5	3
2	2	1	3	5	4
3	3	4	2	5	1
4	4	1	5	3	2

Weights for 5 Criteria

Sl. No.	Fuzzified Weights
1	0.2
2	0.111111
3	0.177778
4	0.177778
5	0.155556

Fig. 10: Preference Function Values and Weights

$$W_j = (\min_j + avg_j + \max_j)/3 \tag{2}$$

Next, the values as obtained from the seven agents are shown in Fig. 11. The preference index and the outranking flows are calculated following expressions (3), (4), (5) and (6). The value of Φ is calculated by expression (7) (Fig. 12). Since higher the value of Φ, higher is the preference of the alternative, thus the ranked alternatives in the descending order are: A2 → A1, A2 being the highest ranked alternative and thus the next best neighbor is 3.

$$\pi(a,b) = \sum_{j=1}^{C} W_j P_j(a,b) \tag{3}$$

$$\pi(b,a) = \sum_{j=1}^{C} W_j P_j(b,a) \tag{4}$$

$$\phi^{+}(a) = \frac{1}{(n-1)} \sum_{x \in A} \pi(a,x) \tag{5}$$

$$\phi^{-}(a) = \frac{1}{(n-1)} \sum_{x \in A} \pi(x,a) \tag{6}$$

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{7}$$

Path length	Number of jobs from source node to neighbors	Number of jobs from neighbors to neighbors of neighbors	Deadlock status	Number of hops
36	7	1	0	5
30	6	6	0	3

Fig. 11: Data Values from Agents

Outranking Flows

Alternatives	Φ^{+}	Φ^{-}	Φ
A1	-0.733335	0.733335	-1.466667
A2	0.733335	-0.733335	1.466667

Fig. 12: Preference Index and Outranking Flows

4. CONCLUSION

This paper proposes a routing strategy for manufacturing networks where, instead of establishing a point-to-point connection between source and destination nodes, a job or message is routed to the next optimal neighboring node. A hierarchical multi-criteria multi-agent based system is considered with a master agent and several worker agents for the proposed routing strategy. The number of worker agents is same as the number of criteria considered for decision making of the master agent. In this paper, a total of five criteria have been considered to determine the next optimum node to route a particular job. These criteria are – 1) shortest path length between the each of the immediate neighbors and the final destination, the number of jobs on route between the current node and each of the immediate neighbors, the number of jobs between each of the immediate neighbors and the neighbors of the immediate neighbors, the deadlock status involving the current node and the number of intermediate nodes (hops). The master agent takes all these inputs from the worker agents and selects the best immediate neighbor using a multi-criteria outranking method known as PROMETHEE. The entire idea is based on the mating behavior of a species of spider known as Tarantula. The female Tarantula sometimes eats the male Tarantula just after mating to satisfy the intermediate need for food or for any genetic reason. Specific example has been considered to implement the proposed strategy.

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