Real-Time Distribution System Based on Multi-Agent

Zheng-gang Dan, Lin-ning Cai, Li Zheng

Abstract— **The purpose of this paper is to present a coalition Multi-Agent based model for Real-Time Distribution System (RTDS). This model is based on Contract-Net Protocol (CNP), and an Agent Communication Model is also provided. A two-stage approach is introduced to solve the real time problems: the initial solutions will be generated in stage 1, and its objective is to design least cost routes from one depot to a set of customers, and to service all the customers, while respecting capacity and time window constraints. In stage 2, the Vehicle Agents would decide whether to service new order through negotiation with Scheduling Agent. Finally, the proposed model is detailed, illustrated through a numerical example, experimented on the base of Solomon's benchmark and compared to the optimal solution.**

Index Terms—vehicle routing problem with time window, Multi-Agent system, Contract-Net Protocol

I. Introduction

In the past 40 years, Vehicle Routing Problem (VRP) has been one of the most active research areas in operations research [1]. Researchers always assume that: before the problem would be solved, all the relevant information must be predetermined, including customer, vehicle, traffic, etc. The solvers know all information beforehand, the problem is considered as static and the solution is relatively changeless.

However, due to the existence of uncertainty in the real world, the actual optimal distribution solution on a giving set of relevant information and constrains may be changed for the following, to name a few:

- Changes in the distribution process, including the time change aroused by traffic congestion, damage to the vehicle, etc.
- Changes of customer orders either by adding new orders or cancel of existing orders.
- Changes of required delivery time.

On the other hand, logistics has become more and more helpful for companies to enhance their business competitiveness, as customer needs for "a shorter delivery time, more variety, and small quantity" increase continuously. Thanks for the development of Information Technology (IT), real-time information can be achieved more easily, and many companies spend a lot of money to buy IT equipments. As one of the Fortune 500 companies, Wal-Mart, started in 2005, increases its investment in information technology for real-time process, from GPS technology to RFID technology. The aim is to get real-time information about products and orders, to improve their handling speed and to reduce the overall operation cost.

But how to use the real-time information becomes another important question. If the information can not be handled in time, the IT equipment means nothing. So methods and algorithms need to be researched to give out a useful way to handle the real-time information.

Some researchers have focused on this research. Bertsimas [2], Gendreau [3] [4] have researched the dynamic vehicle routing problem from the point of stochastic process and heuristics methods. Other papers focus on the Multi-Agent system for real-time distribution [5] [6]. In this paper, a two-stage algorithm is presented for the RT-VRPTW. In stage 1, the initial solution based on predetermined information will be generated. Stage 2 will focus on real-time processing of new orders.

This paper is organized as follows: in section 2, static mathematic model of VRPTW will be introduced; section 3 will present the entire Multi-Agent framework; section 4 will introduce the communication between agents; the real-time processing of orders is presented through a simple example in section 5; finally, the paper will be concluded with future research issues in section 6.

II. Mathematic Model

Real-Time Distribution System is researched in this paper. In fact, the static mathematic model is the Vehicle Routing Problem with Time Windows (VRPTW).

In the VRPTW, let $G = (V, E)$ be a directed graph, where $V = \{0, 1, ..., N\}$ is the node set and $E = \{(i, j) : 0 \le i, j \le N, i \neq j\}$ is the edge set. Node 0 is the depot and $C = \{1, ..., N\}$ denotes the set of customers. All the routes must start from the depot, go to other customers and end at the depot. Each node, i $(0 < i \le N)$, has a specified time window, $[e_i, l_i]$. For a customer i, a vehicle may arrive before e_i and wait until e_i to start the service, but it may not arrive after l_i. All vehicles must leave the depot after time e_0 and return to the depot before time l_0. Each customer, i, has a service demand q_i, to be delivered from the depot and a required service time, s_i. w_i is waiting time before servicing customer i. t_i is arrival time at customer i. R_k is total route time for a vehicle route k. Each edge, $E\ (i, j)$, has a travel cost, c_{ij}, and a travel time, t_{ij}. In this paper, we assume that $c_{ij} = t_{ij}$ for all the edges. A set of identical vehicles with capacity Q is given. The total service

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demand of the customers in a route is not allowed to exceed the vehicle capacity *Q*.

The primary objective of the VRPTW is to find a minimal number of routes to service all the customers exactly once while satisfying the capacity and time window constraints(1). For the same number of routes, the secondary objective is often to minimize the total distance traveled or to minimize the total route duration.

Variables:

$$x_{ijk} = \begin{cases} 1, \text{ if the vehicle } k \text{ travels directly from } i \text{ to } j, \\ 0, \text{ otherwise.} \end{cases}$$

$$y_{ik} = \begin{cases} 1, \text{ if customer } i \text{ is visited by vehicle } k, \\ 0, \text{ otherwise.} \end{cases}$$

The mixed integer formulation for the vehicle routing problem is stated as follows:

$$\text{Minimize} \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0,\, j \neq i}^{N} c_{ij} x_{ijk} \tag{1}$$

Subject to:

$$\sum_{i=1}^{K} q_i \sum_{j=0,\, j\neq i}^{N} x_{ijk} \leq \text{Q} \quad k = 1 \ldots K \tag{2}$$

$$\sum_{i=0}^{N} \sum_{j=0}^{N} y_{ik} (t_{ij} + s_i + w_i) \leq R_k,\ k=1,\ldots K \tag{3}$$

$$\sum_{i=0}^{N} y_{ik} = \begin{cases} K, i=0 \\ 1, i=1\ldots N \end{cases} \tag{4}$$

$$\sum_{i=1}^{N} x_{ijk} = y_{jk},\ j = 0 \ldots N; k = 1 \ldots K \tag{5}$$

$$\sum_{i=1}^{N} x_{ijk} = y_{ik}, i = 0 \ldots N; k = 1 \ldots K \tag{6}$$

$$t_j \geq t_i + s_i + t_{ij} - (1 - x_{ijk}) \cdot R_k, i, j = 1 \ldots N, k = 1 \ldots K \tag{7}$$

$$e_i \leq t_i < l_i, i = 1 \ldots N \tag{8}$$

$$t_i \geq 0, i = 1 \ldots N \tag{9}$$

A feasible solution for the VRPTW services all the customers without the vehicle exceeding the maximum capacity of the vehicle (2) or the travel time of the vehicle (3). In addition, each customer can be served by one and only one vehicle (4). Travel time for a vehicle is the sum of the distance traveled by the vehicle including the waiting and service time. Waiting time is the amount of time that a vehicle has to wait if it arrives at a customer location before the earliest arrival time for that customer. Constraints (5) and (6) ensure that the same vehicle visits each customer. The time feasibility constraints for the problem are defined in (7), (8) and (9). The constraint (7) ensures that the arrival time between two customers is compatible. The constraint (8) enforces the arrival time of a vehicle at a customer site to be within the customers earliest and latest arrival times and (9) ensures that the arrival time of the vehicle at a customer location is always positive.

The VRPTW is an important problem occurring in many distribution systems. Some of the most useful applications of the VRPTW include bank deliveries, postal deliveries, school bus routing, etc.

III. Multi-Agent System Framework

A. *Multi-Agent System*

Multi-Agent System (MAS) is widely used in artificial intelligence, distributed systems, software engineering, computer communications and other fields. This system study a group of autonomy, smart and intelligent agents, and how they communicate with each other to achieve a specific goal. This is due to the fact that MAS presents a very intuitive approach in understanding, designing and implementing distributed software.

B. *System Framework*

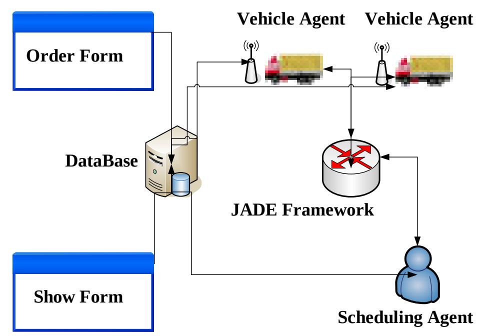

Fig.1 Multi-Agent Framework

Real-Time Distribution System (RTDS) framework is shown in Fig.1, which includes two types of agent: one is Scheduling Agent, and the other is Vehicle Agent. The functions will be described as follows:

- Scheduling Agent, Vehicle Agent, Show Form and Order Form all exchange data through the database;
- Scheduling Agent will make use of the Show Form to display and accomplish the simulation;
- Scheduling Agent and Vehicle Agents will communicate and negotiate based on the JADE Multi-Agent framework;
- Real-time orders and real-time events will also be processed.

The entire framework is based on Contract-NET Protocol (CNP) and KQML language: bidding and negotiation mechanism of agents is based on CNP to determine the optimal solution of VRPTW, the communication of Scheduling Agent and Vehicle Agent is use of KQML language.

Contract-Net Protocol is widely used in various applications, such as distributed artificial intelligence, bidding system, etc. There are two types of agent in the Contract-Net Protocol based system: Scheduling Agent and Vehicle Agent. Scheduling Agent will assign order to Vehicle Agent with methods described as follows (Fig.2):

- When a new order arrives, Scheduling Agent immediately announces the order to all Vehicle Agents;
- Each Vehicle Agent will evaluate this order, and consider if it can perform it while respecting the capacity and time window constraints. Then it will return the result to Scheduling Agent.

- Finally, Scheduling Agent will select the most appropriate value from all the return values, and send an award grant message to this Vehicle Agent.

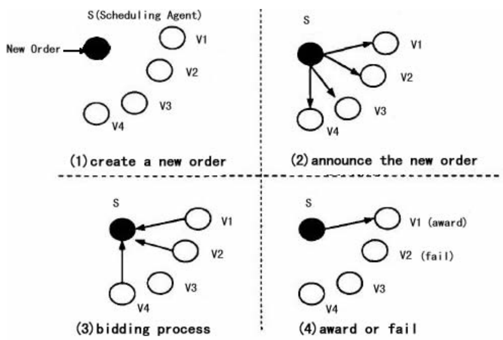

Fig.2 Contract-Net Protocol

C. A two-stage approach

A two-stage approach is used to deal with real-time scheduling for the entire system.

(1) Stage 1

In the first stage, the initial solutions will be generated.

Step 1: Scheduling Agent will generate K Vehicle Agents, usually according to $\sum q_i/Q$ to compute the expected number of vehicles.

Step 2: Scheduling Agent will read an order existed and not assigned from database, and send to Vehicle Agents one by one.

Step 3: Vehicle Agents will evaluate whether they can service this order in violation of constraint (capacity and time window). If so, the increased cost with the new order will also be calculated. The result will be sent back to Scheduling Agent.

Step 4: Scheduling Agent will obtain all the information from the Vehicle Agents, and select the most cost effective one and send the confirmation message. If all the current Vehicle Agents could not successfully service the new order, Vehicle Agent K+1 will be generated and assigned with the new order. Then repeat step 2 until all orders are completely assigned.

(2) Stage 2

The second stage is simulation stage. Vehicle Agents will service all orders assigned to them one by one. Scheduling Agent will monitor real-time if a new order is created, if so, Scheduling Agent will repeat the first stage of the bidding process and assign the new order to a particular Vehicle Agent. If no new order is created, the simulation system will be a stable state.

IV. Communications and Negotiations between Agents

Scheduling Agent and Vehicle Agent communicate and negotiate by use of KQML language.

A. KQML language

KQML (Knowledge Query and Manipulation Language) is one part of ACL (Agent Communication Language), which is Multi-Agent communication standard proposed by FIPA (Foundation for Intelligent Physical Agents), and used to support interaction between Agents for distributed artificial intelligence research.

KQML has been accepted as a standard of agent communication and widely used at present, which defines the standard syntax of information transmission between agents. Key Words of KQML are described in Table.1.

Table.1 Key Words of KQML

parameter	type	meaning
:sender	<word>	sender of request
:receiver	<word>	receiver of request
:from	<word>	original sender
:to	<word>	original receiver
:reply-with	<word>	mark of reply message
:in-reply-to	<word>	mark before reply message
:language	<word>	language name in content
:ontology	<word>	ontology name in content
:content	<expression>	real message content

B. Negotiation process

The negotiation process between Scheduling Agent and Vehicle Agents will be described in detail as below. Here, a number of Vehicle Agents are included in the real-time distribution system (named: VAGENT1, VAGENT2 ...), and a Scheduling Agent is also included (named: SAGENT).

(1) Initialization

Scheduling Agent will generate a number of Vehicle Agents according to the existed static orders, and every Vehicle Agent will be registered in JADE DF (Directory Facilitator).

(2) Order Announcement

If Scheduling Agent can read a new order from the database, it will get all Vehicle Agents from JADE DF, and announce the order to them. (The message send to VAGENT1 is give out only)

(announce
: sender SAGENT
: receiver VAGENT1
: reply-with SAGENT- VAGENT1-ann1
: in-reply-to VAGENT1-adv
: content "[Order1]")

(3) Bidding Process

When VAGENT1 receives the message, it will evaluate the order, and return the evaluation value to Scheduling Agent. The message of "bid" is corresponding to the message of "announce". "IF-Service" denotes whether to service the order, and "bid-value" denotes the bidding value.

(bid
: sender VAGENT1
: receiver SAGENT
: reply-with VAGENT1-bid1
: in-reply-to SAGENT- VAGENT1-ann1
: content "[Order1, IF-Service, bid-value]")

(4) Order Awarding

If VAGENT1 can service the new order and its bidding value is the best one, it will be selected to service this order by Scheduling Agent, and a KQML message of "award" will be sent also. (To other Vehicle Agents, the message is "fail")

(award
: sender SAGENT
: receiver VAGENT1

: reply-with SAGENT- VAGENT1-award
: in-reply-to VAGENT1-bid
: content "[Order1]")

(5) Order Executing

VAGENT1 will get the message of "award" and insert the new order into its order list, then execute it at the appropriate time. Vehicle Agents which get message of "fail" will do nothing.

V. Computational Experiments

RTDS is built up on the Windows XP operating system. JADE is used as the Multi-Agent communication framework for development. In order to verify the effectiveness of procedures, a Solomon [7] example is used as the source of initial orders. Fig.3 is the distribution of these customers (orders).

Multi-Agent System will generate the initial solution based on Contract-Net Protocol as previously described. Fig.3 shows the result. The total cost is 861, which is 3.9% more than the optimal result as we know [8].

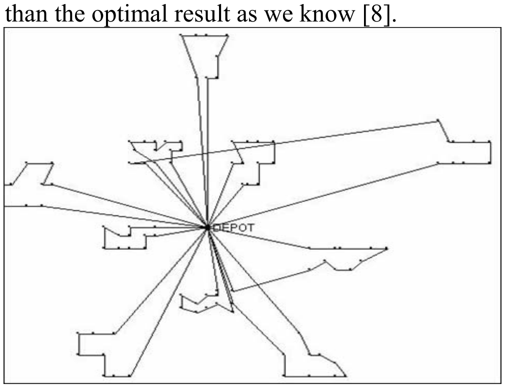

Fig.3 Distribution of customers and initial routes

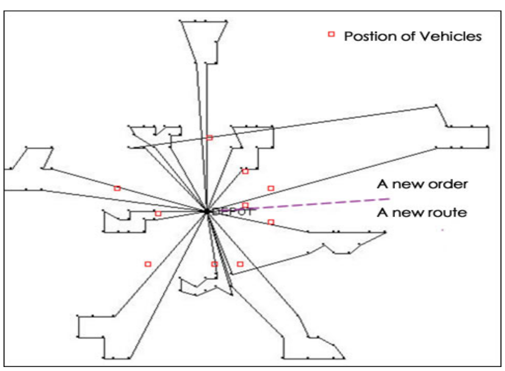

Fig.4 create a new order and a new vehicle

Then the simulation system will begin to work, which means that the Vehicle Agents begin to service the order assigned in their list one by one, and follow by customer service queue. At the same time, if a new order is created, the Vehicle Agents will obtain this new order through bidding mechanism. If all Vehicle Agents can not service the order, Scheduling Agent will generate a new Vehicle Agent to service the order, shown in Fig.4.

If one Vehicle Agent can service the new order, the order will be added to the Vehicle Agent's path, and be serviced before long (Fig.5).

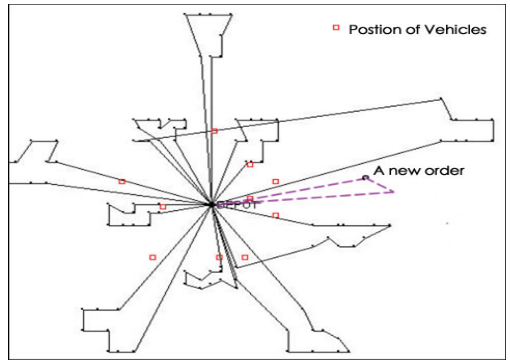

Fig.5 create a new order and adds to one existed route

VI. Conclusion

A Real-Time Distribution System framework based on Multi-Agent is presented in this paper. The bidding mechanism of framework is based on the Contract-NET Protocol to determine the optimal solution of VRPTW. Scheduling Agent and Vehicle Agents communicate by use of KQML language. A Solomon example as a final test data is used to generate the VRPTW initial solution in this paper. And Real-Time order will be created by simulation platform to test the ability of real-time processing. The results show that the framework can effectively handle static orders and real-time orders.

References

[1] Parfaits H N. Dynamic vehicle routing: status and prospects [J]. Annals of Operations Research, 1995, (61): 143-164.

[2] Bertsimas D J, Simch-Levi. A new generation of vehicle routing: robust algorithm s, addressing uncertainty. Operations Research, 1996, (44): 286-304.

[3] Gendreau M, Guertin F, Potvin J Y, et al. Parallel tabu search for real-time vehicle routing and dispatching. Transportation Science, 1996, (33): 381-390.

[4] Gendreau M, Potvin J. Dynamic vehicle routing and dispatching. In: Crainic T G, Laporte G, eds. Fleet Management and Logistics. Boston: Kluwer Academic Publishers, 1998. 115-127.

[5] Boudali, I., W. Fki. How to deal with the VRPTW by using Multi-Agent coalitions. Proceedings - HIS'04: 4th International Conference on Hybrid Intelligent Systems. 2004, 416-421.

[6] Davide, G., Massimo, P., Roberto, S. A dynamic routing strategy for the real-time management of a fleet of tank trucks. IEEE International Conference on Systems, Man and Cybernetics, Oct. 2004, Vol. 6, pp. 6250-6255.

[7] Solomon, M.M. Algorithms for the Vehicle Routing and Scheduling Problems with Time Window Constraints, Operations Research, 1987, (35): 254-264.

[8] Braysy, Olli; Hasle, Geir; Dullaert. A multi-start local search algorithm for the vehicle routing problem with time windows. European Journal of Operational Research, 2004, (159): 586-605.