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Clustering in Autonomous Cooperating Logistic Processes

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Abstract

Due to the growing complexity of logistic processes, “Autonomous Cooperating Logistic Processes” are considered as a way to handle this complexity growth (Scholz-Reiter et al. 2004). In this concept, knowledge and decisions are distributed among the participants of the logistic process. Vehicles and goods become intelligent, interactive, and capable of deciding about how to achieve their aims.

Logistic components may have common aims, e.g., several goods that are at the same location and have the same destination. In such a case, it can be sensible to form communities of those components and determine a community leader that acts on behalf of all members. It is expected that thereby, the required communication among the logistic components can be optimized.

This paper identifies challenges in the area of communication that arise from the distributed decision process and the interacting components. An approach to form clusters among the goods is proposed to address these challenges.

Introduction

The increasing complexity in logistic processes together with rising dynamics has resulted in embedding new technologies or paradigms in the logistic domain. Autonomous Cooperation (AC) is one of the growing paradigms that has witnessed tremendous upsurge in recent years for handling this dynamism and complexity. This paradigm shift is facilitated by the availability of a wide range of information and communication technologies that can be utilised to devolve decision making down to the level of a vehicle and indeed the individual item in the logistic chain [1] [2]. The implementation of AC aims at a flexible self-organizing system structure that is able to cope with the dynamics and complexity while maintaining a stable status [3]. Thus, logistic entities can be defined as items that have the ability to interact and communicate with other entities in the logistic network. Software agent technology is said to provide the means of creating autonomous, intelligent and social software entities capable of supporting autonomous decision making by sharing and interacting with each other. The distribution of planning and decision-making to autonomous components is a widely accepted promising solution to handle complex problems [4]. The motivation comes from the fact that the agent-based systems reflect the distributed nature and are able to deal with the dynamics of execution and planning on the real-time settings [5]. In case of large networks with large number of logistic entities it may result in substantially large communication. So the key challenge is the reduction in the amount of communication to bring about autonomous cooperation in a logistic network. So an approach of clustering the packages first and then routing to finally reach their destination has been introduced in this paper and a result on amount of communication traffic is presented with analytical formulations.

Routing and Clustering Approach

In case of transport logistics, AC means that the vehicles and goods are able to act independently according to their objective such as vehicles try to achieve aims such as cost efficiency while the goods aim to find a fast path to their destination. As the goods need to be transported by vehicles, there is an interdependence between the goods' and the vehicles' decisions. In order to deal with this interdependence, the "Distributed Logistic Routing Protocol" (DLRP) was proposed in [6]. In this protocol, information retrieval is done using route request and route reply messages. In large networks, the route request and route reply messages cause a significant amount of communication traffic. If goods with similar aims can be combined into a community with one "speaker", a reduction of this traffic is expected.

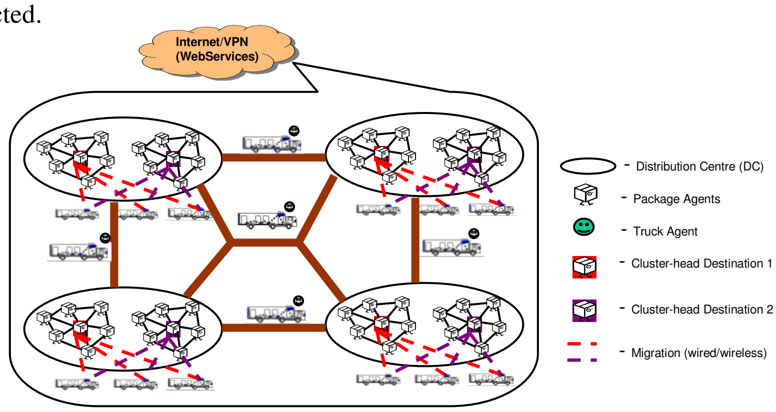

Fig.1. Transportation Logistics: Clustering of Logistic Entities

Logistic entities are represented by software agents, and the solution proposed to reduce the communication traffic is the approach of clustering these logistics entities (software agents). The objective is to cluster the logistic entities which have common goals like packages having the same destination, type of packages etc shown in Fig. 1. Organizing logistical entities into clusters can reduce the communication overhead associated with each of the individual entities and provide scalable solutions. The data associated with the package agent (like the destination ID) can be used as a reference to form clusters by performing intra-communication (communication within packages of same destination) and inter-communication (communication between various cluster-heads). Once the cluster is formed, a cluster-head can be selected to act on behalf of the cluster members instead of the individual entity communicating with each other. Thus, the cluster-head will be the information pool which can negotiate with other entities, for example vehicles. Hence, once the vehicle gets the knowledge of a particular cluster via a cluster-head, it can decide which route is appropriate to reach the destination.

This paper addresses the measure of communication traffic analytically with the approach of clustering and routing of logistic entities. Clustering has been a research topic in various fields of communication networks like sensor networks, ad-hoc networks where all deal with the problem of energy saving (battery life) by reducing communication [7]. The underlying problem in all domains is the same; given a number of objects, a cluster should be created, such that items in the same cluster are more similar to each other than they are to items in other clusters. Since mobile agents are autonomous and intelligent they can be used for creating dynamic and adaptive clusters in a logistical network. So the algorithms applied in the previously mentioned fields can be mapped to logistic networks. For mapping of these algorithms from communication networks, it is necessary to identify where these networks are similar and where they are different.

Clustering can be applied at various levels in a logistical network. Clustering of the packages can be done based on common destinations or type of objects like food, clothing etc. Clustering can also be done by the cities depending on the route taken by the vehicle, or the vehicles itself based on the material they are carrying or destination to where they are travelling via a certain route.

Scenario Description

In this paper, a semi-autonomous scenario is assumed first concentrating on the cluster formation and then routing of the logistic entities. The packages are clustered based on their common destinations. Once the clusters of packages are formed and the cluster-heads nominated (selection of cluster-heads based on different criteria like large lifetime, delivery date etc), the cluster-heads will initiate the routing procedure instead of the individual packages. The amount of communication traffic for the routing procedure with and without-clustering of the packages is measured and compared analytically based on the number of messages exchanged.

Messages sent during clustering

In the clustering procedure, the logistical entities involved are the package agents, the associated vertex (Distribution Centre), and the cluster-heads (after the selection procedure). The messages exchanged between the packages, vertices and the cluster-heads are presented in the Fig. 2. In the initial stage, we assume that, once the package (agent) arrives at its associated vertex, it sends a registration request (RegReq) and gets back a registration acknowledgement (RegAck). The associated vertex on sending acknowledgement looks out for the cluster which has the same destination as for the presently arrived package. Once it finds that the newly arrived package has no clusters based on this destination, it forms a new cluster based on that destination and selects the present package as the cluster-head sending it a message (CHAnn). In case it has a cluster with the same destination, its sends the cluster-head information (CHInfo) of that cluster to the package so that it can register itself with that cluster (CRegReq). In addition, the cluster-head will send back the acknowledgement (CRegAck). The message cluster completion (CComplete) is considered in this scenario based on the cluster size assumed.

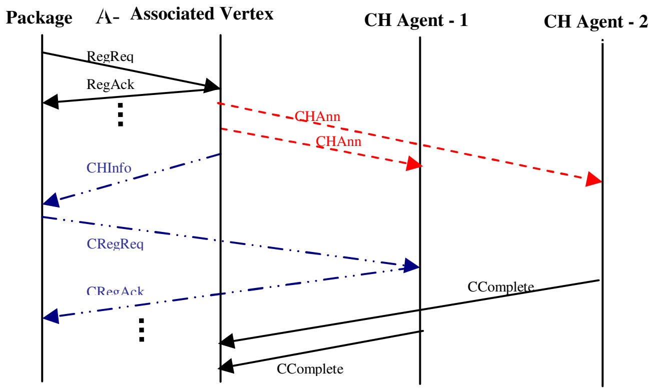

Fig.2. Messages for Clustering

Communication Traffic for Clustering

The total amount of communication traffic for clustering taking into account some assumptions of the message exchange, the number of packages, the number of destinations, the number of clusters and cluster size are presented below.

Representation and Assumption:

Number of packages stored in a DC = N_packs
Number of destinations = N_dests
Number of Clusters = N_Clusters
Cluster size = Cl_size

Total number of Register Request (RegReq) = N_packs
Total number of Register Acknowledge (RegAck) = N_packs

Cluster-head Announcement / Information:
Total number of Cluster-head Announcements (CH_Ann) = N_dests
Total number of Cluster-head Information (CH_Info) = N_packs – N_dests

Clustering Process:
Total number of Cluster Register Request (CRegReq) = N_packs – N_dests
Total number of Cluster Register Acknowledge (CRegAck) = N_packs – N_dests

*Total Clustering Volume = (5 * N_packs - 2 * N_clusters)*

where $N\_clusters = N\_dests * \lceil N\_packs / (N\_dests * Cl\_size) \rceil$

Messages sent during routing

During the routing process in DLRP, the entity (package or vehicle) that performs the routing generates a high amount of data traffic. As there are usually more packages than vehicles and clustering should be applied to the packages, only the package routing is covered in the following. The routing process is illustrated by the Fig. 3.

The routing starts with two queries to the associated vertex and the corresponding responses. These queries inform the package about some initial parameters such as destination, associated vertex etc that it needs for the routing. Then the package sends a route request (RREQ, exactly one) to its associated vertex, which in turn adds some data to the request and forwards it to all neighbour vertices, thus it is multiplied by the vertex's branching factor, which states how many neighbours are available as recipients of the forwarded route request. This is continued until the request reaches the destination or its hop limit. A route reply (RREP) is then sent back for each request that reaches the destination.

Assuming an average branching factor b and an average route length of l hops, the amount of route replies is b^{l-1}, while the total number of route requests sent in the network is $\sum_{i=0}^{l-1} b^i$.

After having received the route replies, the package decides the route and announces it to the affected vertices, which leads to other l route announcements (RANN) per route, so if the package announces n alternative routes, the total number of route announcements is nl

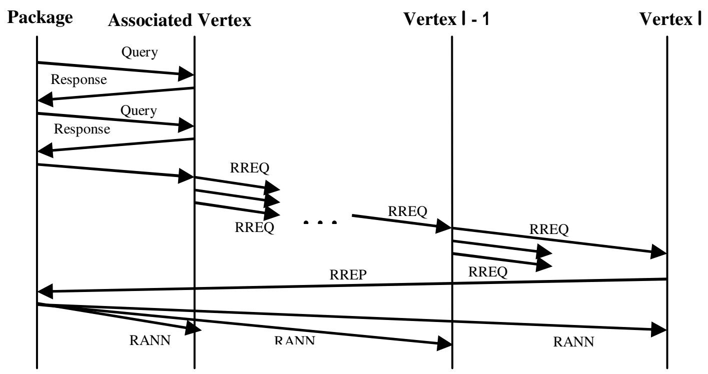

Fig.3. Messages for Routing

For a small logistic network with a branching factor of 3 and packages choosing 3 alternative routes, an average route length of 4 would correspond to 40 route requests and 27 route replies for a single routing process, as depicted in Fig. 5. If for a network the average route length is just one more i.e. 5 then this would lead to huge increase in routing traffic (121 route requests and 81 route replies).

In the case where each package routes individually, each package generates this amount of messages. In contrast, if the routing is only done by one cluster head instead, only the cluster head generates the messages. Therefore, clustering brings a reduction of routing messages by a factor of Cl_size when compared to the non-clustered case.

The assumptions with respect to number of packages, number of vehicles is presented in the Table. 1.

Parameters	***Representation***	***Value***
Number of Packages	N_packs	Min 50 Max 500
Number of Destinations	N_dests	5
Route Length	l	Min 3 Max 7
Branching Factor	b	Min 1 Max 8
Number of alternate routes	n	3
Cluster size	Cl_size	Min 2 Max 20

Table.1. Parameters for Clustering and Routing

Results

The results depicted in Fig. 4, 5 and 6 give the total amount of communication traffic taking into account clustering and routing messages for varying number of packages, route length, and branching factor, respectively. The set of curves are presented for the parameters such as *Without clustering,* varying *Cluster size*, and *No cluster size limit*. As seen in Fig. 4 the communication traffic goes on increasing linearly with increasing number of packages and is of maximum value in the case *Without Clustering*, while the communication volume decreases gradually with the increase in the cluster size. Fig. 5 depicts the results for varying route length, and it is observed that the communication traffic has its maximum value in case of *Without clustering* and the result is similar for the case of varying branching factor as presented in Fig. 6. This implies that as the route length and branching factor increases the amount of communication traffic increases substantially but not as high as compared to the increase in the number of packages.

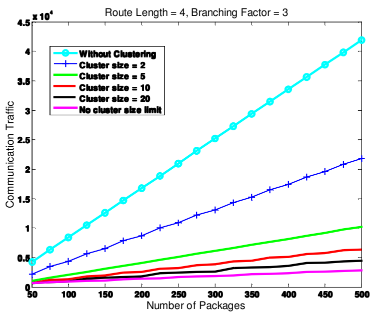

Fig.4. Communication traffic vs. Number of packages

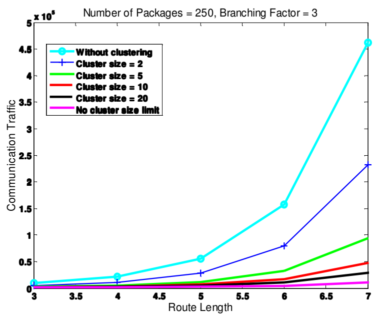

Fig.5. Communication traffic vs. Route length

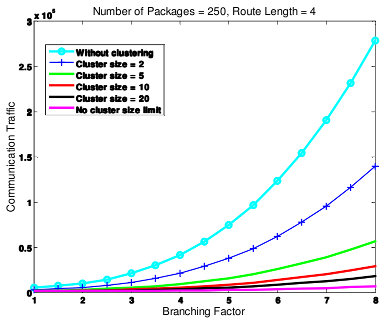

Fig.6. Communication traffic vs. Branching factor

Hence, it can be concluded that clustering of the entities helps in reducing the communication volume depending on the size of the clusters. The larger the cluster size, the less the communication between the logistical entities will be as only one of the members needs to communicate on behalf of all others whereas there will be a slight increase in the communication within the cluster members to form the clusters.

Summary and Outlook

In this paper, the communication-related challenges of autonomous cooperating logistic processes were briefly introduced, and a cluster-based approach to reduce the communication volume was proposed. Some results are presented with respect to the communication volume with varying number of packages, route length, and branching factor. This approach will be investigated by simulation in the near future, expecting a significant improvement in communication efficiency.

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