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Efficient Communication in Autonomous Logistic Processes by Application of Cluster-based Routing Methods

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Abstract

Autonomous cooperation in a logistical network means autonomy for each of the individual entities with increased flexibility and robustness. This autonomy can be achieved with the help of software agents. Once autonomous, logistical entities need to perform their own decisions. For autonomous packages this means that they themselves search and then select the optimal route. To reduce the drawbacks of message flooding mechanisms involved in route search, clustering of packages can be performed. This paper gives an overview of a clustering-based routing approach applied in a logistical scenario and implemented using a multi-agent based simulation system. A performance evaluation on the expected communication traffic associated with clustering and routing is presented. The results obtained show the inter-dependence of clustering and routing to optimize communication traffic.

1. INTRODUCTION

In this work, the concept of clustering logistic items based on the common attributes they share is modeled using a software agent framework. Various parameters based on which logistic items can be clustered are, for example, destination, origin, geographical region, route, price, type of goods like temperature dependent or prioritized with respect to life time of delivery etc. Therefore, the clustering algorithms should be able to identify the criteria for clustering depending on the need of the logistic network and hence adapt accordingly. Also, the use of representing logistic entities by software agents and the role it plays in bringing about autonomous cooperation is addressed. In addition, the benefit of clustering the logistical entities needs to be ascertained.

Bringing autonomous cooperation into a logistical network involves giving autonomy to each of the individual entities with increased flexibility and robustness. Autonomy means that each individual vehicle or piece of good can make decisions on its own, according to its individual goals. For example the flow of goods is no longer controlled by a central instance. Instead the package finds its way through the transport network to the destination autonomously while constantly communicating with the conveyances and nodes and considering demands, e.g. concerning the delivery date and costs [1].

The software agent framework plays the most promising role with regard to the ability of logistic objects to coordinate and decide by them. Intelligent software agents can fulfill different functions in logistic processes like representing individual logistic objects and the related objectives or mediating the coordination process between other agents [2]. A software agent is a piece of code or a software program which can be static or mobile depending on the user application. An agent performs various tasks autonomously on behalf of the user. The agents are assumed to be embodied in an environment, to act autonomously, and be able to sense changes and react appropriately [3]. These agents use different interaction protocols for communication by exchanging messages which helps in efficient information exchange between them. For example the packages, vehicles etc. can communicate and negotiate among themselves about their destination and which route they need to travel on, etc. But a single logistic entity cannot handle all the joint negotiation and decisions by itself and additionally in case of large logistical network, implementing this approach result in overwhelming requests and responses which lead to substantial communication overhead. Thereby, the required communication between the autonomously cooperating logistic components needs to be optimized along with efficient negotiation capabilities.

Communication optimization can be achieved by reducing the number of messages exchanged between the logistic

entities. Efficient negotiation and decision making can be handled by choosing a “capable entity” which is able to make decisions on behalf of all but with consent of every other entity. Thereby, clustering can be seen as one of the best possible solutions to handle this problem, where in the chosen cluster-head will be the “capable entity” to make negotiation within the clusters and take decisions on the behalf of all other cluster members. In addition clustering reduces the communication overhead as now only the cluster-head communicates on behalf of other cluster members.
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In section 2, the background related to multi-agent systems in logistics and the basic motivation behind this work is presented. A framework for agent-based simulation of logistic routing is discussed and the motivation for cluster-based routing is presented in section 2.2. In section 3, the clustering approach is discussed and the analytical evaluation of routing and clustering related communication traffic is presented in section 4. Scenario description is addressed in section 5. The analytical and simulation results are presented in section 6 with the conclusion and outlook in section 7.

2. BACKGROUND

In this section, the survey of multi-agent systems in logistics and the distributed logistics routing protocol is discussed in detail.

2.1. Multi-agent systems in Logistics

Transportation logistics play a vital role in the success of an organization. The ability to transport goods quickly and cost effectively is seen as a vital factor for an organization. In transportation logistics, atomization of transport processes along with congested traffic infrastructure lead to highly dynamic and complex logistic processes [1]. Additionally these complexities and dynamics can also be caused by the changes in orders, information shared, etc, resulting in completely new routes. The arising complexity and dynamics in logistic networks put forward a great challenge for the organizations.

The vision of the Collaborative Research Centre (CRC 637) “Autonomous Cooperating Logistic Processes” is to equip logistic processes and logistic objects with the capability to take decisions autonomously [4]. Within the CRC 637 the paradigm of Autonomous Cooperation was introduced by the research group at University of Bremen. To handle the increasing complexity in logistic processes together with the rising dynamics by autonomous cooperation, information and communication technologies like RFID, agent technology, communication networks’ paradigms are integrated in the logistics networks to achieve better planning and management solutions [5]. The idea of making use of these technologies is to move the decision making down to the level of an individual item in the logistic chain i.e., a vehicle, container or even a package. This requires that every item in the logistical network has to be autonomous, reactive and communicative to participate in the intelligent negotiation and decision-making process.

The innovation in supply chain management, logistics and distribution systems design reflects the general tendency of increasing interest towards cooperative Multi-agent systems within large-scale distributed organizations [6]. Multiagent-based simulation (MABS) attracts increasing attention in the context of complex simulations with potentially great numbers of parallel and interacting sub-processes [7]. In fact, MABS are well suited to distributed applications that require representing problems that have multiple perspectives and problem solving entities. This enables distributed simulation [8] as well as natural mapping of logistical entities to software agents with proper autonomy encapsulation. The research area of agent technology continues to yield techniques, tools, and methods that have been applied or could be applied to the area of logistics [9].

The software agent’s paradigm has much to offer in terms of dynamics involved in the logistic networks. This dynamic process involves constant flow of information and materials across multiple functional areas both within and between different organizations. Several agent-based approaches have been proposed to deal with the dynamic optimization problems in transport logistics [10]. The motivation comes from the fact that the agent-based systems reflect the distributed nature and are able to deal with the dynamics of planning and execution on the near real-time settings [11]. Hence, the objective is to identify the challenges and potential of integrating agent technology and knowledge management approaches to ensure robust and efficient planning and scheduling in the transportation domain.

2.2. Distributed Logistics Routing Protocol

In case of transport logistics, Autonomous Cooperation means that the vehicles and goods are able to act independently according to their objective, i.e. 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 [12] as shown in Figure 1. An agent based framework for adaptive routing is modeled and implemented in the software agent simulation tool “Platform for Simulation with Multiple Agents” (PlaSMA) [13] (developed by the researchers of the CRC 637 at the University of Bremen). This simulation tool provides a distributed multi-agent simulation platform intended for the simulation of logistic processes with autonomous entities. It is based on the FIPA-compliant Java-Agent Development Framework JADE [15].

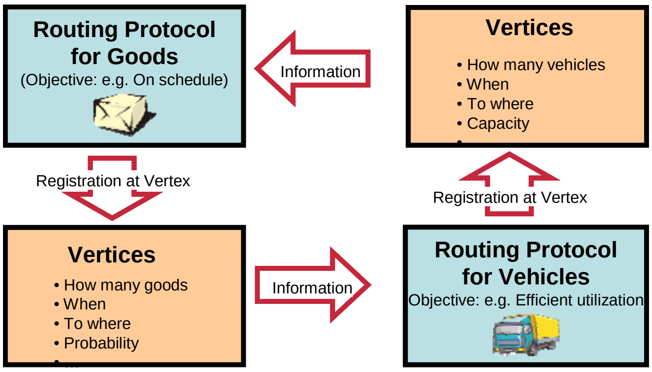

Figure 1: Distributed Logistics Routing Protocol Approach

In PlaSMA, every autonomous logistic item like package, vehicle, distribution center (node) etc. is represented by a software agent. Each of the individual logistic entities can communicate with each other in order to perform their tasks autonomously. For example, packages can find route to the destination individually and can do the negotiations with the vehicle regarding the route traversed. Distributed Logistics Protocol Approach is depicted in Figure 1. In this approach, initially the vehicles and the goods register with the vertex. The information, for e.g. on the schedule of goods delivery, the vehicles on the high load etc is also exchanged with the vertex. Once the vehicles and the goods register with the vertex, the vertex will in turn inform the respective goods and vehicles about the number of goods, their destinations and the capacity etc. Thus, once the information is exchanged, the vehicles and goods start the routing process. DLRP is based on the concept of ad-hoc routing protocols which are deployed in infrastructure-less communication networks.

The advantage of giving autonomy to each and every logistical entity is that it will result in every item communicating and negotiating to perform its tasks in an optimum manner. But in some cases, such as logistic networks with large number of entities, it will result in an enormous communication traffic. For example in the routing process, each of the packages or vehicles floods the route information throughout the network which may result in a large amount of communication. The communication traffic should be reduced by keeping the exchange of messages concentrated within the local proximity of the logistic entities. This can be done by means of clustering similar logistic items together. Section 3 provides a detailed overview of the clustering approach applied on a logistic scenario and the advantages associated with clustering.

3. CLUSTERING APPROACH

This section addresses the clustering approach proposed for a logistics network. Clustering is a well known concept that has been studied in a variety of fields in the literature. Here the concept of clustering is being deployed on a logistic scenario.

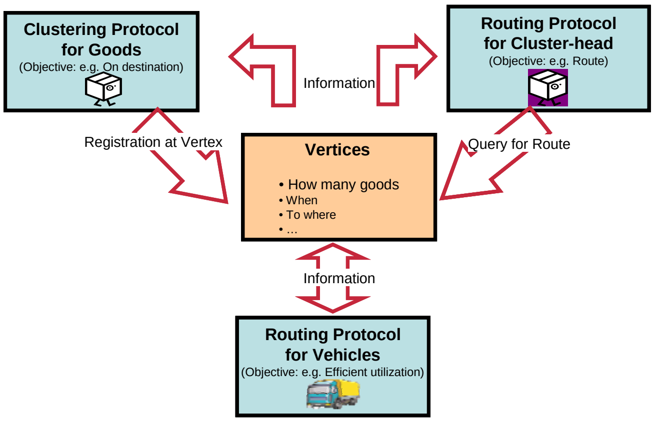

Figure 2: Cluster-based Distributed Logistics Routing Approach

For example in a logistic network, certain logistic entities 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 reasonable to form communities of those entities and determine a leader with certain capabilities more than the other members like higher lifetime, later delivery date etc. The cluster-head acts as the information pool for its cluster members and can initiate as well as handle the negotiations within the cluster members and take decision on behalf of them depending on the responsibility or capability transferred to it.

As depicted in Figure 2, the approach of clustering is modelled and implemented in the agent-based framework PlaSMA along with the concept of DLRP. The idea behind this approach is, instead of individual goods starting the routing process, a cluster of goods is formed with respect to a common destination and the cluster-head initiates routing on behalf of all the other packages within the cluster. So in the case with cluster-based routing, the goods register with the vertex and then the vertex forms the various clusters based on the common destinations of the goods. When the clusters are formed, a cluster head is selected (in this case the first member that registers with the vertex becomes the cluster-head). Once the cluster-head has enough members, it will then start the routing process similar to an individual good in case of DLRP. Thus, on behalf of all other members the cluster-head initiates routing. Thereby, the amount of communication traffic associated with all the individual entities finding individual routes to the destination is reduced to the case where in now only the cluster-head has to find the routes. Thus, the amount of communication is reduced to larger extent in case of cluster-based routing than only routing process.

4. ANALYTICAL EVALUATION

4.1. Messages sent during routing

During the routing process in DLRP, the entity (package or vehicle) that performs the routing generates a significant 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 Figure 3.

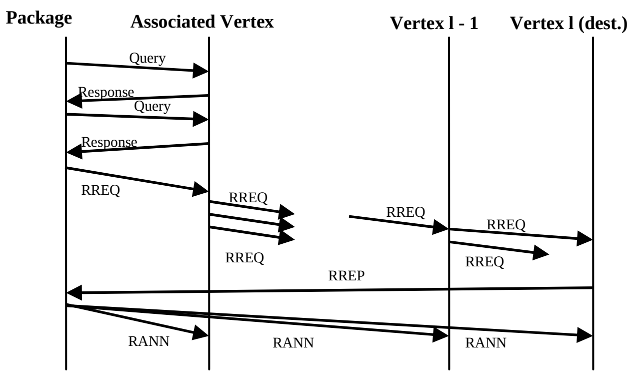

Figure 3: Message flow in DLRP routing

The routing starts with two queries to the associated vertex and the corresponding responses (i.e. 4 messages). These queries inform the package about some initial parameters 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 (available transport capacity, estimated handling times etc., depending on which parameters are used for route decisions) 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 a hop limit of l hops, the total number of route requests sent in the network is $\sum_{i=0}^{l} b^i$. The number of route replies depends on how many of the paths that the requests travelled lead to the destination. Assuming m paths led to the destination, this is also the number of replies. The maximum possible number is $m_{\max} = b^l$.

After having received the route replies, the package selects the favourable routes and announces only these selected routes to the affected vertices. This mechanism/operation leads to $l+1$ route announcements (RANN) per route. Since not all of the replied routes may be selected by the package, the package announces n alternative routes ($n \le m$), and the total number of route announcements will be $n(l+1)$. In case of more than one announced route, there are also route disannouncements (not depicted in Figure 3): Once one route is definitely taken when the package is loaded to a vehicle, the other alternative routes are disannounced. Therefore, the total number of disannouncement messages will sum up to $(n-1)(l+1)$.

The total message count from one routing process is therefore $N_{routing} = 4 + \sum_{i=0}^{l} b^i + m + (2n-1)(l+1)$. 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.

4.2. Messages sent during clustering

The messages exchanged during the clustering process are illustrated in Figure 4.

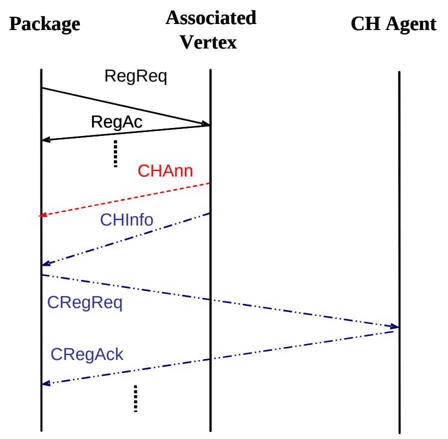

Figure 4: Message flow for Clustering process

The clustering process starts by exchanging the registration request (RegReq) and Acknowledgement (RegAck) messages between the package and the associated vertex. These messages inform the associated vertex with the initial parameters it needs to start the clustering process such as the destination of the package etc. Once the package gets registered with the vertex, the associated vertex looks if there is already a cluster formed with the presently registered package destination and sends the cluster-head information (CHInfo) message (blue arrow) of that cluster to the package. Then, the package registers with that cluster-head with the Cluster register request (CRegReq) message, and the cluster-head acknowledges with the cluster register acknowledge (CRegAck) message. In case that there is no cluster available for that destination, the associated vertex sends a cluster-head announcement message (CHAnn) to that particular package (red arrow). On reception of the CHAnn message, the package itself becomes the cluster-head.

The total number of RegReq and the RegAck equals the number of packages (N_{packs}). The total number of CHAnn equals the number of destinations (N_{dests}) or number of clusters ($N_{clusters}$). The total number of cluster-head information messages is $N_{packs} - N_{clusters}$.

Once the clusters are formed, the total number of CRegReq and the CRegAck also equals the $N_{packs} - N_{clusters}$ respectively.

Thus, the total clustering traffic is given by

$$TotalClusteringVolume = 5N_{packs} - 2N_{clusters}$$

where $N_{clusters} = N_{dests} \left\lceil \frac{N_{packs}}{N_{dests} Clustersize} \right\rceil$.

5. SCENARIO

To evaluate the clustering algorithm's performance and compare the analytical results for the expected communication traffic to simulation results, some sample scenarios with different characteristics were chosen.

In all of the scenarios, packages are generated until a maximum package number, the generation limit, is reached. Then the generating agent stops itself. The total generation rate in each source of each scenario is 20 packages per hour of model time, i.e. if there is only one source, 20 packages per hour are created in the scenario, in case of s sources, the total generation rate in the scenario is s*20 packages per hour.

As described in the previous section, the clustering is done by the vertex (the distribution center) which adds packages with the same destination to an existing cluster until either the cluster size limit is reached or a timeout occurs. The cluster is then closed and the cluster head initiates the routing process. Due to the timeout, it is assured that after termination of the package generation, the remaining open clusters get closed and can start the routing as well.

The following scenarios, despite being displayed on a real map and labeled with real city names, are artificial scenarios that were created to have specific topology parameters, especially related to the branching factor and the route hop count.

Figure 5 depicts a scenario with a topology that consists of two disconnected parts. The sources are located at the vertices labeled “Bremerhaven”, “Kiel”, “Luebeck” and “Schwerin”. Thereby, each routing starting at one of the sources experiences a branching factor of 1. The destinations are chosen such that the hop count from source to destination is 2.

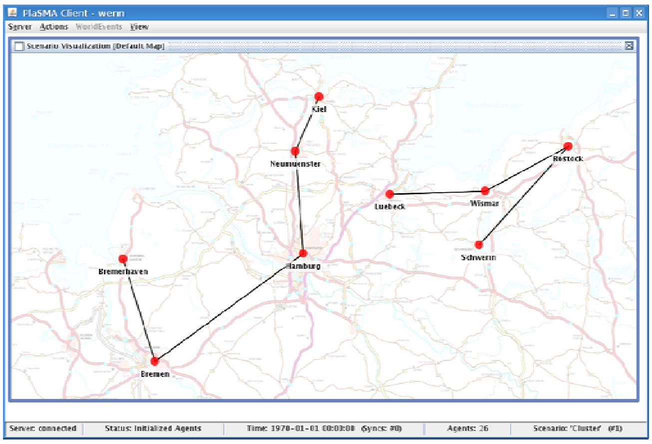

Figure 5: Scenario with branching factor 1 (Topology-1)

The topology in Figure 6 is the next step with respect to the branching factor: With respect to the sources “Hamburg”, “Kiel”, “Rostock” and “Guestrow”, each routing experiences a branching factor of 2. All locations that are at 2-hop-distance from a source are destinations for packages created at this specific source.

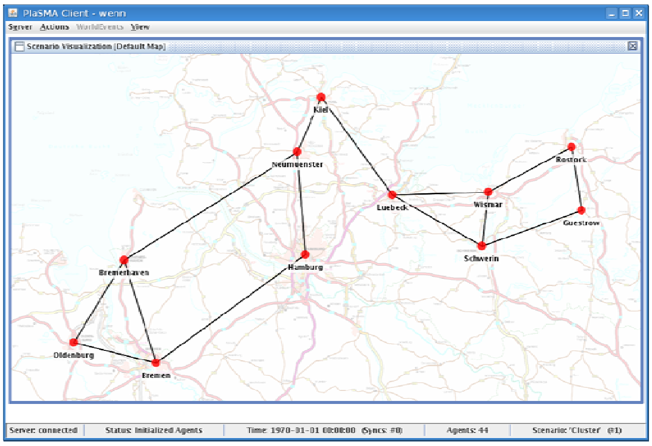

Figure 6: Scenario with branching factor 2 (Topology-2)

Figure 7 depicts a more realistic scenario that is based on connections through highways and major roads. It can be seen that real topologies usually have inhomogeneous branching factors throughout the map. This makes it harder to obtain an analytical formulation on how many messages are exchanged, but simulation results (see Figure 10) have shown that the benefit of clustering is still very much present.

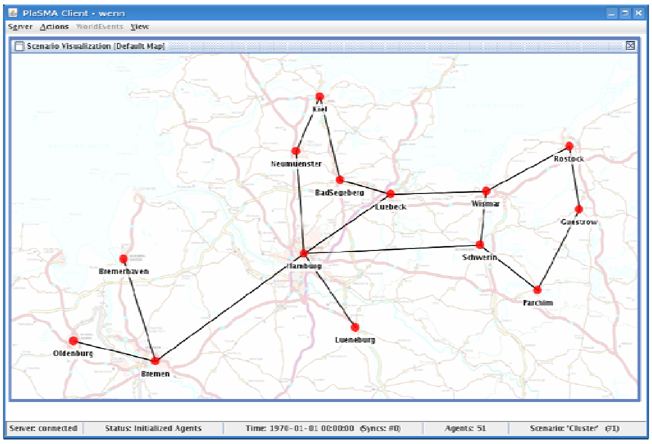

Figure 7: More realistic scenario based on road/highway connections

6. RESULTS

Routing packets increase with increase in network parameters such as branching factor, route length, number of alternate routes to the destination, etc. A larger branching factor (bf) or route length (l) means more flooding of the route request packets in the network, whereas a larger number of alternate routes lead to more route reply, announcement and disannouncement messages.

The diagrams in Figure 8 and Figure 9 depict the simulative and analytical results representing the total amount of communication traffic associated with routing and clustering processes for varying number of packages.

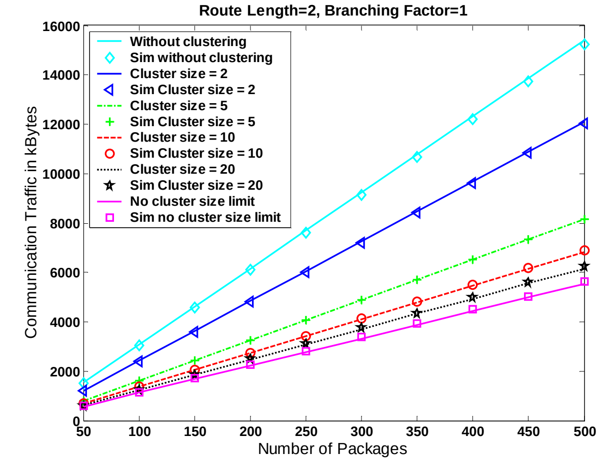

Figure 8: Communication Traffic versus Number of Packages with route length =2, Branching Factor =1: Topology-1

The curves represent the communication traffic for different cases such as *Without clustering* (communication traffic associated with only routing), *Varying cluster size* and one with *No Cluster size limit*. The latter implies that the cluster size can be infinite and cluster formation is only limited by a timeout. In the simulation implementation, the limit is set to be equal to the number of packages being generated at the vertex.

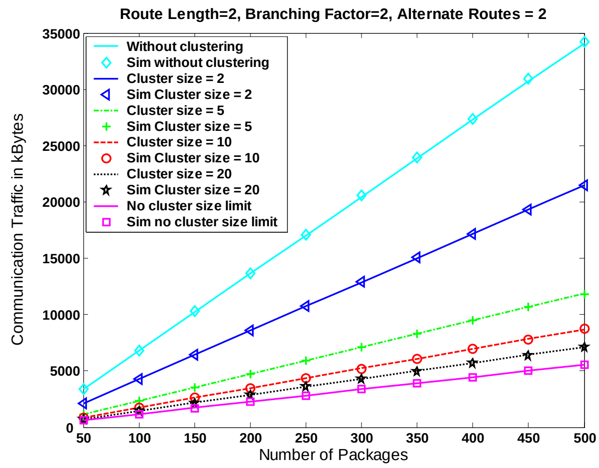

Figure 9: Communication Traffic versus Number of Packages with route length =2, Branching Factor =2: Topology-2

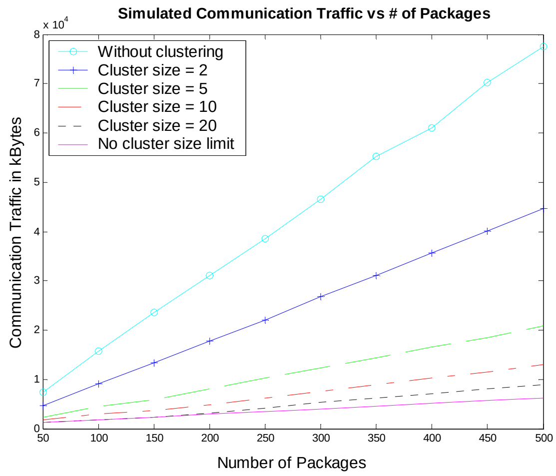

Figure 10: Simulated Communication Traffic versus Number of Packages for a realistic scenario

In Figure 10 a more realistic logistic scenario is depicted with source destination pairs not chosen just to keep a fixed branching factor or route length. Since in a true logistic application, it is hard to determine the branching factor, only the simulation results are depicted for this topology. Figure 8 and Figure 9have shown that the analytical results match with the simulation results and hence results presented in Figure 10 can be relied upon.

As seen in the figures, as the number of packages increases the communication traffic increases linearly in all cases. But, the communication traffic is maximum in case of *Without clustering* and additionally as the cluster size increases, the communication traffic decreases, the lowest curve is the case of *No Cluster size limit*. This implies that, the higher the number of members in a formed cluster is, the less becomes the communication traffic as the cluster-head is the one that handles the communication on behalf of all other members.

In addition, clustering aids in reducing the influence of large values of network parameters such as branching factor, route length, etc. By clustering, only cluster-head packages initiate routing and thereby the saving potential with respect to communication traffic increases with network complexity. For e.g. the clustering gain for Topology-1 with bf = 1 is 1.22, in case of Topology-2 with bf = 2 it is 2.92 and for the realistic topology with arbitrary branching factor it is 4.92 for 400 packages and a cluster size of 10. The clustering gain is defined as the ratio of ‘the reduction in communication traffic by clustering’ and ‘clustering communication traffic’.

Thus, cluster-based routing shows better performance than routing without clustering processes. As observed in the figures, the analytical results also match the simulation results.

7. CONCLUSION AND OUTLOOK

In this paper, modeling of a cluster-based routing approach in a logistical scenario using an agent-based framework is proposed. The description of clustering and routing approaches implemented in the agent-based simulation tool PlaSMA is described. The analytical formulations for clustering and routing messages are presented and the results are compared with the simulation results. Results (both analytical and simulative) obtained with respect to different topologies are presented. In addition, simulation results are presented for a more realistic logistical scenario based on the road map.

It can be concluded by the results that for autonomous logistic processes, a cluster-based routing approach results in less communication traffic than a routing approach without clustering. The simulative results obtained by the implementation in the agent-based simulation tool matches with the analytical results. Hence, the simulated results are validated and the conclusion can be drawn that in case of large autonomous logistical networks, clustering of entities results in reducing the communication traffic to an enormous extent.

As future work, investigations can be made with respect to different topologies. Improved definition of cluster formation timeouts with respect to time constraints of goods can be studied which would aid in analyzing the influence of clustering on logistic performance e.g. punctuality and efficient vehicle utilization etc. Additionally, the affect of lower and upper bound of cluster size on the logistic performance like end-to-end delay of the packages to reach the destination, etc needs to be analyzed. Further investigations on issues concerning dynamic updation of clusters based on the spatial location and mobility of agents as the simulation unfolds must be considered. Different advanced clustering methods like multiple criteria usage can be modeled and implemented with the agent-based framework for further analysis.

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