Influences of Communication Disruptions on Decentralized Routing in Transport Logistics

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Abstract: - The increase of complexity and dynamics leads to new challenges in transport logistics networks. Current routing algorithms of central control are pushed to their limits in handling these new challenges. This leads to the development of an autonomously controlled routing protocol, the Distributed Logistics Routing Protocol (DLRP), which allows a better handling of the new requirements. Within the DLRP, the logistic entities perform routing decisions on their own. For that a high degree of knowledge exchange between the logistics entities is essential. Within the work presented in this paper the influences of communication disruptions are investigated. Communication disruptions can lead to partial knowledge for the logistic entities, which has negative influences on their routing decisions. This paper presents the influences of different degrees of communication disruptions on the routing processes.

Key-Words: - Autonomous control - Distributed logistics routing protocol (DLRP) – Transport logistics – Routing algorithms – Communication disruptions

1 Introduction

Actors in logistic networks share information in order to fulfill their own tasks. In networks of transport logistics different actors need information like order data, traffic data, etc. If the information transfer is disrupted, the execution of transport orders can be constricted. The aspect of information transfer is also very relevant for the Distributed Logistics Routing Protocol (DLRP), which has been developed within the Collaborative Research Centre 637 (CRC 637) [9]. This is a decentralized routing method, which is adapted from data communication algorithms. The DLRP enables logistic entities to render their own routing decisions in transport logistics networks. For that, they have to share information with other logistic entities. If the information transfer is disrupted, the logistic entities have only partial knowledge, which influences the routing decisions negatively. Possible reasons for disruptions of the communication transfer are technical problems, due to defected technologies for communication or overloads in the communication traffic. They can occur unexpectedly in the whole logistic network.

Within this work the influences of communication disruptions, due to technical problems, are evaluated in different scenarios. The evaluation in different scenarios allows the investigation of general aspects of communication disruptions. These kinds of investigations are often performed for algorithms and protocols of data communication networks. As the DLRP is based on algorithms of data communication, it is reasonable to consider such analyses. Important performance indicators measured during these analyses can be compared to logistic target values of transport logistics networks. Several researchers who have already analyzed technical effects in communication networks considered different indicators, inter alia packet loss and delay statistics. These indicators are comparable to the ratio of delivered transport goods and the delay statistics for their delivery. In [2] different routing protocols (DSDV, TORA, DSR and AODV) have been compared. An important aspect of the comparison has been the ratio of delivered routing packages, in order to evaluate maximum throughput of the considered network. In [3] the analyses of [2] have been extended for the protocols DSDV, DSR and AODV. Here, further network topologies were utilized. Furthermore, additional target values have been measured, e.g. the packet delay through the network. Another protocol has been considered in [8]. In the mentioned paper the MBone, a multicast network, is presented and analyzed. The topic of interest has been packet loss statistics, in order to examine spatial and temporal correlations.

2 The Distributed Logistics Routing Protocol

The Distributed Logistics Routing Protocol (DLRP) is a decentralized routing method. It is based on the assumption that transport vehicles and transport goods in a logistic network are equipped with devices capable of computing and communicating. Thereby, they are able to interact and decide autonomously. The basic concepts of the DLRP are adapted from routing algorithms that are used in wireless ad-hoc communication networks, where routes have to be found in a dynamically changing topology.

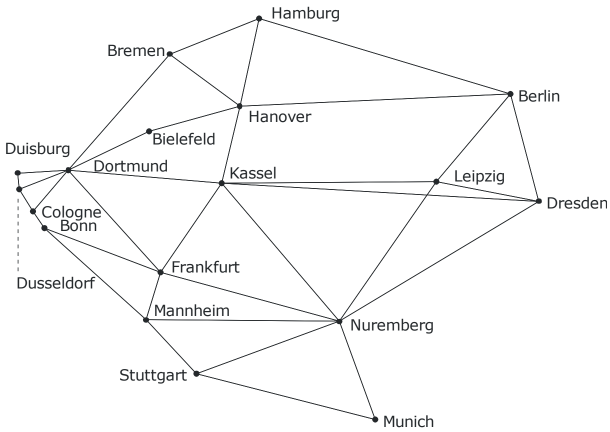

Fig. 1: Scenario topology

Basic topologies of scenarios for the DLRP consist of a graph with vertices, which represent logistic distribution centers, and edges between these vertices. The edges represent road connections. A sample topology is presented in Fig. 1. The figure has already been published in [1]. It illustrates a simplified map of Germany. The graph contains 18 cities of Germany and important motorways between the cities.

In order to plan routes, transport vehicles and transport goods communicate via using a route discovery messaging. For that, data packets are transmitted. By transmitting these packets, the logistic entities exchange knowledge for their decisions. When planning a new route, a logistic entity sends route requests to the neighbored vertices. The requests contain the destination vertex of the logistic entity. Each vertex, which receives the route request and which is not the destination, adds its local knowledge about the current network status to the route request. This knowledge includes, inter alia, information about announces routes of other logistic entities. Following, the route request is forwarded to neighbored vertices. When the destination vertex receives the route request, a route reply is generated, which contains the collected knowledge of the route request. The reply is transmitted directly to the logistic entity.

A hop counter is part of the route request transmitting process. If the number of vertices on the actual route exceeds a hop limit, a route reply for the actual route cannot be transmitted. Hence, the route is no more considered. Furthermore, loops are avoided when transmitting route requests. For that, only vertices that have not received a route request yet receive the new route request. The only exception is the destination vertex, which can receive several route requests. Hence, several route replies are transmitted to the logistic entity, each reply contains knowledge about a specific route. The logistic entity renders its routing decision after receiving several route replies. The decision depends on the collected knowledge for the possible routes and on the decision criteria of the logistic entity. A possible criterion for transport goods is the delivery time or the length of a route, for example. For transport vehicles, a high utilization is a possible criterion. The decision criteria of the logistic entities can be adjusted to the specific scenario. When a decision is rendered, the route is announced at the vertices on the route. The vertices use this knowledge for routing processes of further logistic entities. Rerouting of the logistic entities is possible. If a better route can be discovered, old routes expire, then the previous route announcements are cancelled. Further details concerning the DLRP are described in [7].

The DLRP has been evaluated against heuristic methods that are applied to solve the Vehicle Routing Problem (VRP) [4] and the Pickup and Delivery Problem (PDP) [6]. These algorithms are used for classical logistic routing scenarios. There are some important differences between the DLRP and the before mentioned algorithms. For example, planning within the DLRP is executed dynamically, whereas the compared algorithms generate a-priori plans. Due to the differences, the algorithms have been compared within previous work, with some essential adjustments. The results show a good performance of the DLRP [5].

3 Communication Disruptions

Within this work, communication disruptions, due to technical problems, are simulated. This concerns the communication via route requests and route replies. By transmitting these messages, the logistic entities gain essential knowledge for routing decisions. The occurrence of technical problems leads to disruptions of the information transfer. Hence, the logistic entities do not have full information about all possible routes, which leads to an interference with the routing decision.

Technical problems are difficult to predict: They can occur throughout the whole logistic network, often without immediately apparent reasons. To investigate the influences of these uncertainties, different degrees of communication disruptions have to be simulated for the whole network.

For the simulation of communication disruptions, the information transfer for the routing processes has to be affected. For that, it is essential to block the transmission of several route requests and route replies. This has been achieved by integrating a threshold for the forwarding decision. If a route request / reply has to be transmitted along a connection to the next vertex, a random value will be generated, which is called the disruptions calculation. If this value is higher than the threshold, the routing message will be forwarded. The threshold can be varied. Hence the influences of different degrees of communication disruptions can be simulated in order to evaluate the robustness of the DLRP against different degrees of disruptions. Low degrees of disruptions lead to a high percentage of transmitted messages, whereas high degrees lead to a low percentage of transmission. It is assumed that the disruption degrees (and consequently the thresholds) for all connections in a logistic network are equal, independent of the source and the goal of the particular route. In future work the influences of heterogeneous disruption degrees will be investigated.

Concerning communication disruptions, an important difference between route requests and route replies is the number of transmissions. Route requests have to be forwarded along the vertices. At each transmission of a route request between two vertices, a communication disruption can occur. Assumed that the probability for a blocked route request is equal for each connection between two vertices, the opportunity that a request arrives at the destination vertex can be calculated for each route n:

$$i_n = (1.0 - p_{req})^{V-1} \qquad (1)$$

preq is the probability for the disruption of a single route request, V is the number of vertices on the actual route. For each new vertex, a route request has to be transmitted. An important aspect of the DLRP is the hop limitation (section 2). If the number of vertices (and essential route requests) on the route exceeds the hop limit, the route cannot be announced. Hence, it is possible to calculate the probability that a route can be announced in spite of the possibility of disruptions of route requests:

$$i = 1.0 - \prod_{n=1}^{N} (1.0 - i_n) \qquad (2)$$

i is the probability that the route discovery is successful for at least one route, whereas N is the number of routes for that an announcement is possible. The part with the multiplication sign calculates the probability that no route request can be transmitted to the destination vertex, independent of the concrete route.

In contrast to route requests, route replies are transmitted directly to the receiver of the reply. Therefore the disruption calculation for a route reply has to be performed once, the result determines if the route reply is transmitted or not. This leads, in comparison to the disruptions of route requests, to a higher probability for a successful transmission. If a route reply is disrupted, another route reply has to be chosen for an announcement of a route. Due to the fact that the route replies contain the whole knowledge about possible routes, there are many differences between their qualities. If another route reply has to be chosen, it is possible that the logistic target values will be negatively influenced in a high degree, e.g., resulting in longer route distances, fewer already announced logistic entities, etc. Therefore, the negative influence of a disrupted route reply is potentially higher than the influence of a disrupted route request.

4 Evaluation

4.1 Scenario description

Within this work, the influences of communication disruptions on the logistic performance are investigated. The influences of the disruptions are evaluated in scenarios with a topology that represents a simplified map of Germany (Fig. 1).

Twelve transport vehicles are integrated into the scenario, each with a capacity for twelve transport goods. 1000 transport goods are generated dynamically within the scenario. The last good is dispatched at a simulation time of 39, the maximal due time for each of the goods is 25 time units. According to this information, the last good is assumed to be delivered not later than at a simulation time of 64. Hence, a minimal time limit for the simulation runs of 64 is essential, the goods are assumed to be delivered within this time.

Because of the implementation of communication disruptions, delays can occur, which leads to longer delivery times for goods. Due to this reason, an extended time limit of 75 has been chosen, in order to offset possible communication disruptions.

The implementation of communication disruptions is evaluated by several simulations. The disruptions of route requests or of route replies is simulated, on the one hand for each of the logistic entities (transport vehicles and transport goods), on the other hand for both entities simultaneously. For the disruption of route replies and of route requests, different simulation runs are performed.

The communication disruptions are simulated in degrees intervals of 3%, from 0% to 100%. For each interval, ten simulation runs are performed. The degree of communication disruptions is homogenous over the whole network: for each disruption calculation, the same threshold is utilized. The investigation of the influences of heterogeneous disruption degrees is topic of future work.

4.2 Evaluation results

The evaluation results are presented within the following figures. The figures show the number of delivered transport goods within the simulation time and the delivery time. The x-axis of each figure represents the disruption degree, whereas the y-axis represents the particular logistic target value. Three line charts are presented within each figure. The first line chart represents the results for simulations, where communication is disrupted for transport vehicles and goods simultaneously. The second and the third line chart show the results for disruptions for only transport goods or transport vehicles.

4.2.1 Disruptions of route requests

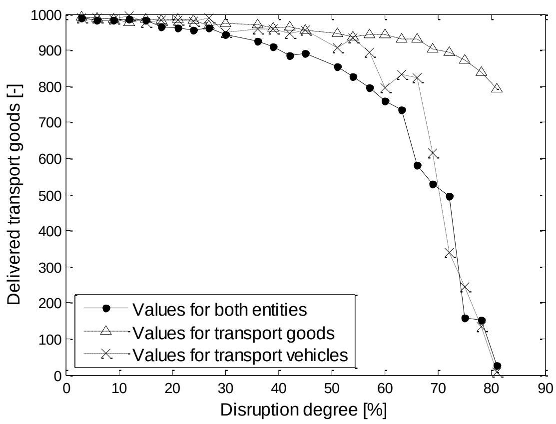

Fig. 2: Delivered transport goods for the disruption of route requests

First, the results for the disruptions of route requests are presented. Fig. 2 shows the number of transport goods that are delivered within the simulation time, in spite of disrupted route requests.

The figure shows that the number of delivered transport goods decreases with increasing disruption degrees. Because of the communication disruptions, transport goods have to announce longer routes with higher delivery times, hence many goods cannot be delivered within the simulation time. This leads to decreasing numbers of delivered transport goods. At high disruption degrees, it is even possible that many transport goods cannot announce a route at all. The reason is that the route requests of a high number of transport goods do not arrive at the destination vertex, due to too many communication disruptions. This is presented in the figure from a disruption degree of ~50% onwards. Above that degree, the values for disruptions for vehicles or both entities decrease rapidly. This shows that the negative influence of communication disruptions is higher, when the information exchange for vehicles is disrupted. If the degree is higher than 50%, the vehicles cannot plan their routes to deliver the transport goods successfully. The negative influence of disruptions for transport goods is smaller. At disrupted communication for transport goods, the goods have to announce detours. Nevertheless, the transport vehicles are able to deliver many goods in time.

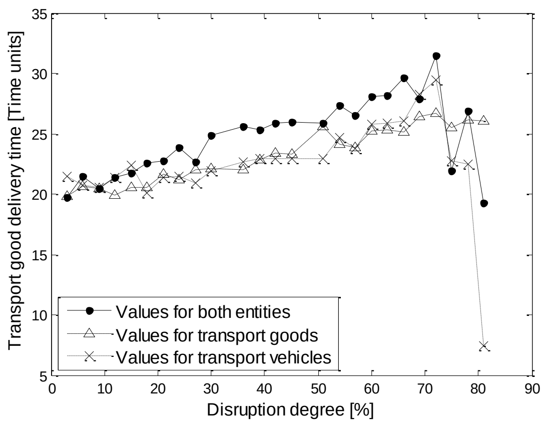

Fig. 3: Transport goods delivery time for the disruption of route requests

In Fig. 3, the delivery time is presented, the value concerns successfully delivered transport goods during the simulations. The delivery time has been measured in simulation time units. It can be seen that the values for the target value increase in the case of disrupted route requests for transport goods.

At disruption degrees from 60% - 70%, the values stagnate. Transport goods, which have to announce long detours due to communication disruptions, cannot be delivered within the simulation time. These goods are not taken into account for the calculation, which, in turn, results in smaller values for the delivery time. The values for disruption communication for vehicles and both logistic entities simultaneously are influenced in the same way like the values for goods. The fact that the information exchange for transport vehicles is also disrupted leads to decreasing values due to the non-delivery of transport goods, which is described before. The transport goods generated within the simulations are expected to be delivered within 25 time units. If the disruption degree is too high (~70%), the delivery time limit is expired.

4.2.2 Disruptions of route replies

As described in section 3, another kind of communication disruptions within the DLRP is the disruption of route replies. In the following, the results for the simulations are presented.

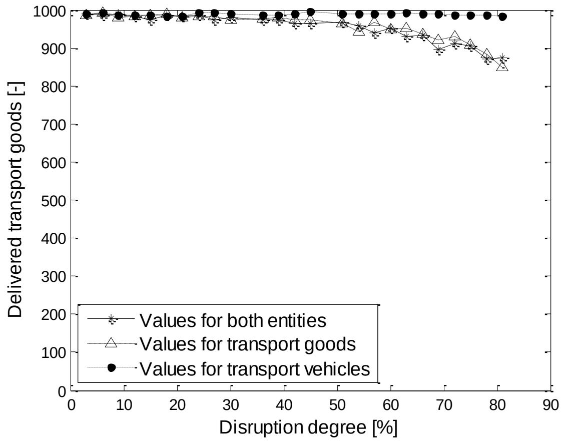

Fig. 4: Delivered transport goods for the disruption of route replies

Fig. 4 shows the number of transport goods that have been delivered within the simulation time. The results are stable, if only the information exchange of vehicles is disrupted. In spite of these disruptions the vehicles are able to announce their routes. The DLRP balances the disadvantages through disruptions of route replies by reallocating the transport vehicles to other routes. This results in the possibility to deliver nearly all transport goods. In contrast, if the information exchange for transport goods is (also) disrupted, the number of delivered goods decreases from a disruption degree of 60%. The reason is that the goods have to announce longer routes, in many cases it is not possible to deliver all goods within the simulation time.

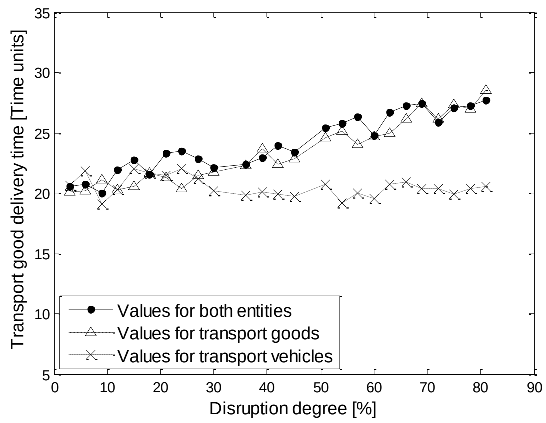

Fig. 5: Transport goods delivery time for the disruption of route replies

In Fig. 5, the values for the delivery time are presented. The figure shows the values for successfully delivered transport goods. In the case of disrupted communication for vehicles, the values for the delivery distance are constant. Reallocation of the vehicles influences these values in a marginal extent. In contrast, the values increase if (also) route replies for transport goods are disrupted. Longer routes and higher delivery times are the effects.

5 Conclusion

Within this paper, the influence of communication disruptions has been evaluated. The communication disruptions have been simulated for route requests and for route replies. Until a disruption degree of 50%, the influences on routing processes are low. Hence, the DLRP is able to handle disruptions of communication until that degree.

Comparing the results for route requests against the results for route replies, the DLRP is more robust against disrupted route replies. Disadvantages, caused by disrupted route replies, have only marginal negative influences on the logistic performance.

In future work, simulations of heterogeneous degrees of communication disruptions are interesting. Here, the influences of communication disruptions at individual vertices will be investigated. Furthermore, the influences of communication disruptions are investigated in scenarios that exhibit a higher complexity.

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