Scholz-Reiter, B.; Rekersbrink, H.; Freitag, M.: Internet routing protocols as an autonomous control approach for transport networks. In: Teti, R. (eds.): Proc. 5th CIRP international seminar on intelligent computation in manufacturing engineering. 2006, pp. 341-345

Internet Routing Protocols as an Autonomous Control Approach for Transport Networks

B. Scholz-Reiter, H. Rekersbrink, M. Freitag
BIBA at the University of Bremen, Hochschulring 20, 28359 Bremen, Germany

Abstract
To realise an autonomous control for transport networks it is attempted to transfer well known and approved routing protocols from data communication to transport problems. Here structural differences between data and transportation networks prevent a direct transfer of the protocols. In transportation networks not one but several diverse and particularly adapted protocols are needed, which have to cooperate in spite of different targets. In the following a cooperative routing concept for transport logistics called 'Distributed Logistics Routing Protocol' is introduced, developed within the Collaborative Research Centre 637 'Autonomous Cooperating Logistic Processes' at the University of Bremen.

Keywords:
Logistics, Transport, Autonomous Control, Routing

1 INTRODUCTION

The growing dynamics and complexity of logistics systems lead hierarchical planning and control architectures to their limits. One way to handle these circumstances is to shift from a central control to decentralised, autonomous control strategies. The concept of autonomous control is the main research area of the German Collaborative Research Centre 637 'Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations' (see [1], [2]).

In case of transport logistics, routing and the assignment of transport orders to vehicles are normally done centrally by a human dispatcher aided by a dispatching system. Mostly, the dispatching itself is considered as a static problem. This is solved either by the use of heuristics or by applying rules that are gained from experience.

In the following, a completely different approach for dealing with these primarily dynamic problems in transport logistics is investigated. One opportunity to implement a dynamic autonomous control strategy for transport networks is to transfer existing routing protocols from data communication. Some kind of autonomous control for data streams was required since the beginning of electronic data communication. In this case, central planning and control was and is impossible due to the size of the communication networks.

2 TRANSFERRING ROUTING PROTOCOLS

For the transfer of routing algorithms from communication to transport networks it is necessary to identify analogies and differences between these networks. Obvious similarities are the transport of an item from a source to a sink and the existence of many possible routes for this transport. The crucial point is the adequate choice of one of these routes. Bigness and dynamic of both networks are also comparable.

But there are significant differences between communication and transport networks.

On the one hand vehicles are needed in logistic networks to do the transport of a package. They have no counterpart in communication networks. Both objects (vehicles and packages) are mobile and need routes for themselves, which normally differ from each other. Additionally different goals have to be considered for the decision on the route.

- Not only one but two routing protocols are needed for transport networks.
- The two protocols have different decision criteria.
- Nevertheless the protocols have to work as one to optimise the whole network.

A second difference shows up in the different time scales of the nets. In communication networks routing process and data transmission take similar time intervals within the range of milliseconds. The transport of goods in contrast takes a lot longer than any routing process.

- One cannot assume that the changes of the network can be neglected during the use of the determined route as it is done in data communication. In transport networks, the routing process must respect possible future changes of the net.
- Due to the time scale difference a larger communication effort is possible and meaningful for the collection of the most current information.

Both differences are significant and prevent a direct transfer of existing routing protocols to transport logistics. The algorithms from data communication must be adapted to the special requirements of transport networks and changed crucially. However it has to be ensured that the advantages, e.g. robustness, reliability or low need for maintenance, remain.

These advantages result mainly from the kind of information storage and information collection. In principle distributed systems have no possibility of accessing a central information centre and thus complete information. The crucial point of routing algorithms is the intelligent collection of decentralized information. Enough information for a meaningful route decision has to be collected without producing an exploding communication overhead - the correct balance is the key to success.

Due to these considerations only the information storage and collection structure was transferred in this project. For the actual route decision, own new methods were chosen. Because of time and resource shortages concerning the route decision in communications networks, only very simple decision processes are possible. In transport networks only few restrictions are to be kept. Therefore the decision procedures may be more complex and consider several decision criteria for a better optimization of the whole network.

From the multitude of existing Routing Protocols one decided to take the Dynamic Source Routing (DSR) as basis for the concept of the Logistics Routing Protocol described below (for more information about different Routing Protocols see e.g. [3]).

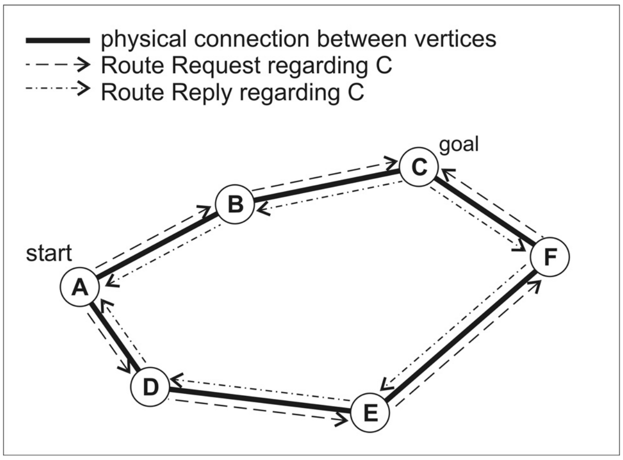

Figure 1: RouteRequest / RouteReply mechanism based on the Dynamic Source Routing (DSR).

This algorithm works as follows (see Figure 1): A vertex only has information about itself and its direct neighbour vertices. If a route is needed for a goal vertex, then the start vertex is asked for a route to the goal (by means of so-called RouteRequests). Since this is not the goal vertex, it forwards the request to its neighbour vertices (see Figure 1: vertex A doest not know the goal, vertex C, and forwards the RouteRequest to it's neighbours). These proceed now in exactly the same way until a route to the goal is found. The goal vertex recognizes itself as the goal and sends back the information collected on the way. This answer is called RouteReply. The start vertex then holds current routes and information up to the goal.

3 CONSIDERATIONS OF THE TIME PROBLEM

In communication networks, a route found by a routing protocol is used to send a package until this package has reached its goal. This implies the assumption that the net does not change during the transport process. As mentioned above, the situation in transport networks is different. The time for the transport itself can be very long, so that a network change must be assumed.

This difference is completely independent from the way how the route is calculated. It is examined in the following.

Figure 2 shows a simple example of a net which edge weights are changing with the time. At t=0 a route with minimum costs from the left to the right corner vertex was (however) calculated. For this calculation only information at the time t=0 is regarded. This route is pursued up to the goal and is not changed, why this method is called 'static routing' in the following. It is evident that this route is not inevitably the optimal route for the entire time.

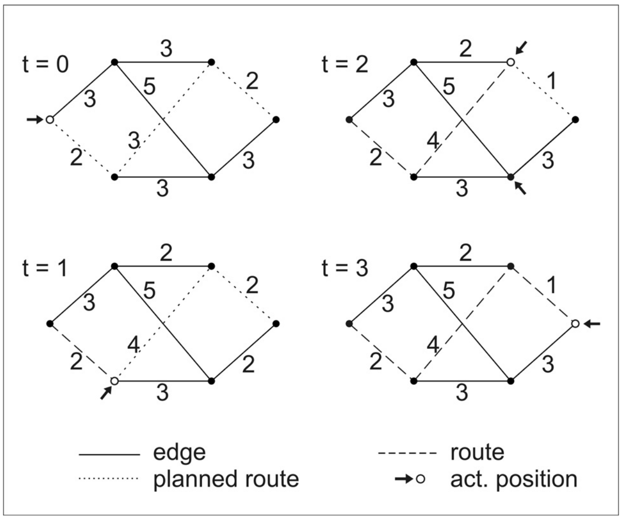

Figure 2: Static Routing.

In order to work against this effect, one can try to determine the optimal route again at each vertex. Such a method is called 'reactive routing', because the route can be changed if the environment has changed. Figure 3 shows this method. At t=0 the optimal route is calculated as above. At the next vertex (t=1), again the optimal route from the actual position to the goal is calculated, considering the actual information. Then the planned route is changed, because the bottom way is cheaper now. However also this procedure does not lead to the total optimum - it leads even to a longer route in this special example.

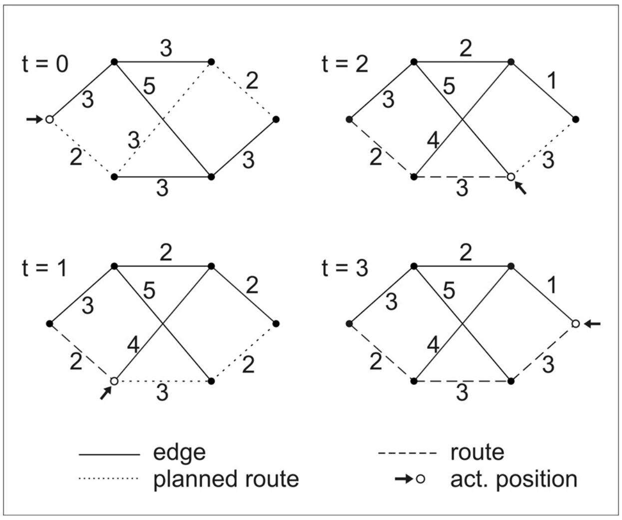

Figure 3: Reactive Routing.

Scholz-Reiter, B.; Rekersbrink, H.; Freitag, M.: Internet routing protocols as an autonomous control approach for transport networks. In: Teti, R. (eds.): Proc. 5th CIRP international seminar on intelligent computation in manufacturing engineering. 2006, pp. 341-345

The logical consequence for routing methods in changing nets is to consider all future net conditions. It is evident that the real optimal route can be found with complete information about all future net conditions (see Figure 4). This route is usually cheaper than the ways determined by the previous procedures.

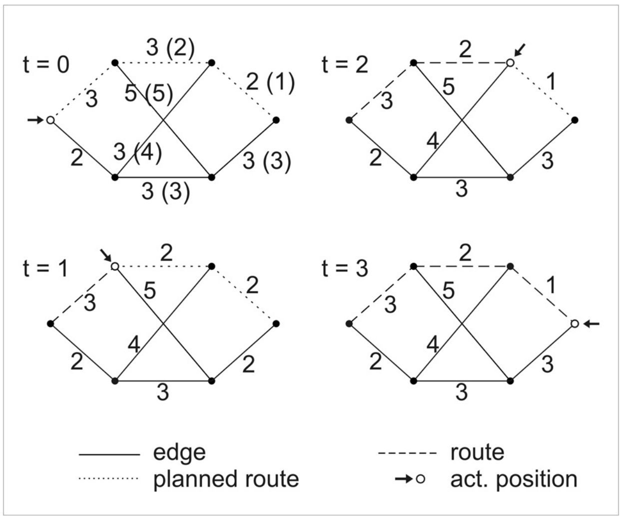

Figure 4: Routing with complete information.

Admittedly, it cannot be assumed that all future network conditions are known in a real transport network. In fact one is dependent on estimations of future data. A routing method with complete information becomes to an 'estimation based routing' in reality.

By means of numeric experiments within the project, it could be proved for small changing nets that, under certain conditions, the estimation based routing can be better than reactive routing methods.

Especially for fast changing nets, a rough estimation of the future conditions is enough for an estimation based routing to be significantly better than reactive routing. Figure 5 shows the qualitative result of the numeric simulations: For changing nets, a nearly linear borderline (which depends on other influences) separates the areas where reactive routing or estimation based routing is better. For a growing rate of change a rougher estimation is needed.

The complete results of the analytic and numeric investigation of this phenomenon will be published shortly.

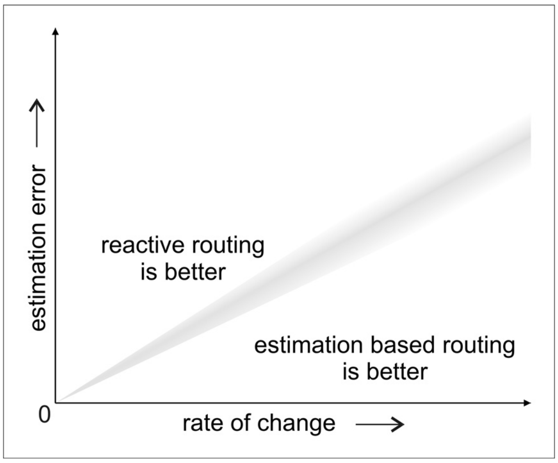

Figure 5: Qualitative areas for routing methods.

For the transfer of routing algorithms from data communication to transport logistics, the algorithms should be used for something like an estimation based routing to solve the time problem. The new protocol should have a possibility to make proper estimations of the future network conditions

4 CONJUNCTION OF ROUTING PROTOCOLS

As mentioned above, a structural difference between communication and transport nets is the amount of object types which need a routing.

In a transport network both the packages, which are transported by the vehicles, and the vehicles, which carry the packages, need a route. Targets and decision criteria for the route choice differ clearly from each other. Packages have a clearly defined geographic goal, which has to be reached within a defined time frame. Route decision criteria for packages could be e.g. punctuality, cooling or restrictions on large vehicles.

In contrast vehicles have no geographical goals. Route decision criteria for vehicles could be e.g. high utilization on the selected route, observance of rest periods or the return to the starting point after a maximum travel time (whereby also vehicles sometimes have goals).

Additionally to different goals and decision criteria both route decisions are connected very closely, because both sides need information about the route decisions of the other side (see Figure 6). A package can determine its own way only if it knows, when and on which edges it can be carried by a vehicle. A vehicle again can determine its utilization on a certain way only by the fact that it possesses information about the package routes. A vehicle has to know where all the packages want to travel in future.

A conjunction of the routing protocols for both object types and thus a cooperation of the objects involved is essential.

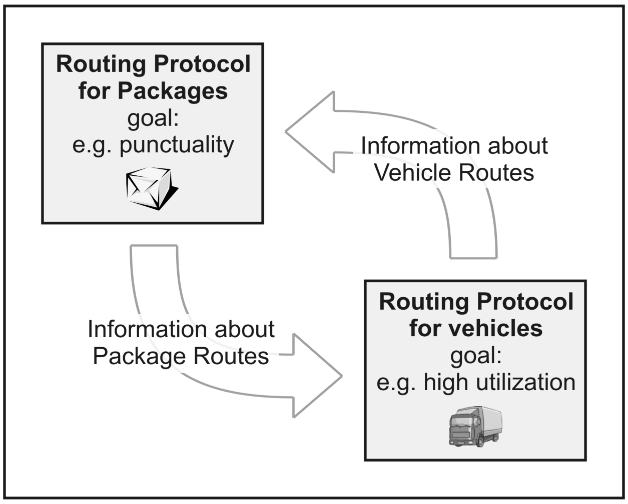

Figure 6: Interdependence of the Routing Protocols.

5 DISTRIBUTED LOGISTICS ROUTING PROTOCOL

This dilemma can be solved only by a form of communication between both object types. For this an indirect communication form is suggested.

In the suggested concept both sides announce their route decisions at the vertices. In this way they can also get necessary information about the route decisions of the other part. The vertices of the logistic net act in their whole as a decentralized information storage.

On the basis Figure 7 the fundamental procedure of developed protocol can be illustrated: When a package makes a route decision, it first disannounces its, possibly announced, old route (see Figure 7: RouteDisAnnouncement) and announces its actual wished route to the vertices involved (see Figure 7: RouteAnnouncement). An individual vertex has thereby information about when how many packages with which goals will be at its position. Additional information such as restrictions concerning the transport of the goods (e.g. cooling freight) is stored likewise.

If a vehicle needs a route, it sends a RouteRequest to the net – the RouteRequest/RouteReply mechanisms are the same as described above. After receiving several RouteRequests, which are route suggestions now, with appropriate additional information, a vehicle decides for a route. This Route is then announced to the involved vertices (see Figure 7: RouteAnnouncement). This leads to a continuous cooperative structure. The objects in a transport net do not plan their route at the same time. Packages emerge continuously or achieve their goals, vehicles replan their routes and so on. At each time there is enough information for any route decision.

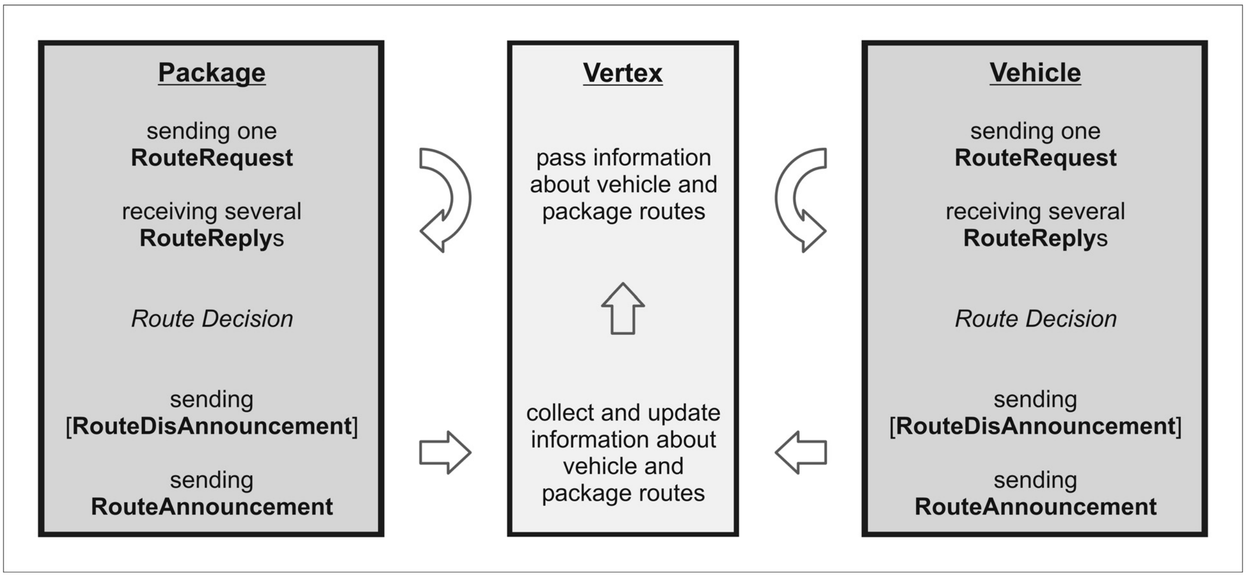

Figure 7: The fundamental structure of the Distributed Logistic Routing Protocol (DLRP).

This introduced routing concept was named '**Distributed Logistics Routing Protocol**' (**DLRP**) (see also [4]). It offers crucial advantages:

Self - Adaptation

The removal from or addition of objects to the logistic network does not mean a replanning. The net adapts continuously to changed situations.

Manual Intervention

It is possible to allocate firm routes manually to a logistic object without obstructing the general optimisation of the net.

Estimation of Future Conditions

The route decision processes need information about future net conditions (see above). As a result of the described Announcement/DisAnnouncement mechanism, these required future net conditions can be estimated very well.

Implicit Uncertain Knowledge

The approach also implies uncertain knowledge: As a package does not really know if a specific vehicle picks it up, it does not just calculate one route, but it looks for a set of alternative routes to increase the probability to reach its destination in time. All these alternative routes are announced to the vertices, so that the announced package routes are just valid with a certain probability. If a package is picked up by a vehicle, alternative routes have to be disannounced again. Vehicles, on the other hand do not necessarily stick to a route they once decided, so the vehicle routes are uncertain as well. If they find a route that is better than the original one, they might change their decision (it depends on their individual settings if they really do), disannounce the old route and announce a new one.

Uncertain information can also be stored and processed. This depends on the chosen decision function, see below.

Arbitrary Decision Processes

The DLRP itself does not specify the functions that are used by the packages and vehicles to decide about their routes. It just specifies the interaction. There are various possibilities for decision making, e.g. fixed rule sets, heuristic approaches, probabilistic approaches, Fuzzy Logic approaches or artificial neural networks. Any decision method can be used – even different methods for two objects of the same type. Some of these options are currently under investigation.

This implies also the following point:

Arbitrary Kind and Quantity of Information

The different decision functions may require different kinds and different amount of information. There is no restriction on the information collected by the DLRP.

6 CONCLUSION AND OUTLOOK

A transfer of routing algorithms from data communication to transport logistics appears meaningful with regard to the similarities of communication and transportation nets. The advantages of a decentralized control by routing protocols can be transferred and agree with the aims of an autonomous control. However, an adjustment of the protocols is necessary due to specific requirements of the transport nets. The required adaptations were outlined.

A fundamental transferability of routing protocols from data communication is already proven by first implementations of simple algorithms into a transport net simulation (see [5]). At present the DLRP is specified in the last details and implemented into a simulation. Hereby the efficiency of the presented routing strategy will be proved.

The vision of the DLRP is similar to wireless Ad Hoc networks. Logistic objects and their goals and specifications should be easy to merge into the logistic network - the rest is done by the network itself.

7 ACKNOWLEDGMENTS

This research is founded by the DFG (German Research Foundation) within the CRC 637 ‘Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations’.

8 REFERENCES

[1] Scholz-Reiter, B., Windt, K., Freitag, M., 2004, Autonomous Logistic Processes - New Demands and First Approaches, 37th CIRP Int. Sem. on Manufacturing Systems – CIRP ISMS ‘04, Budapest, 19 - 21 May: 357-362

[2] Windt, K., Böse, F., Philipp, T., 2005, Criteria and Application of Autonomous Cooperating Logistic Processes, Proceedings of the 3rd International Conference on Manufacturing Research, Cranfield, 6 – 8 Sptember

[3] Perkins, C. E., 2001, Ad hoc networking, Addison-Wesley, Boston

[4] Scholz-Reiter, B., Rekersbrink, H., Freitag, M., 2006, Kooperierende Routingprotokolle zur Selbststeuerung von Transportprozessen, Industrie Management 22/3 (to be published)

[5] Wenning, B.-L., Görg, C., Peters, K., 2005, Ereignisdiskrete Modellierung von Selbststeuerung in Transportnetzen, Industrie Management 21/5