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USAGE OF MOBILE RADIO SERVICES IN FUTURE LOGISTIC APPLICATIONS

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Abstract— **Increased customization of products and their delivery has brought about a fundamental shift in the economical landscape: from markets that were predominantly controlled by sellers to markets that are now driven by buyers and their demands. The concept of autonomous logistic processes intends to overcome these drawbacks together with latest information and communication technologies. The I&C technologies enabling communication for autonomous logistic processes are presented, such as a communication gateway using infrastructure and sensor networks as well as agent technology and distributed algorithms. The algorithms are evaluated using a simulation environment specifically designed to model the relationship between autonomous logistic processes and their communication environment.**

I. INTRODUCTION

Logistics planning and monitoring poses a technically challenging problem. The various types of planning activities include packing, scheduling, and route planning with several constraints. The problem is highly distributed, yet interconnected (as the organisations are autonomous). Dynamic situations enter the system, e.g., in the form of changed logistics requests. The simplest plans involve interaction between the components that are distributed in the logistic networks.

II. AUTONOMOUS LOGISTIC PROCESSES

In research an ongoing paradigm shift from centralised control of non-intelligent items in hierarchical structures towards decentralised control of intelligent items in heterarchical structures especially in logistic processes can be observed. These intelligent items can be all possible logistic objects from raw materials, components or products to transit equipment (e.g., pallets, packages) or transportation systems (e.g., conveyors, trucks) [1].

We assume that both plans and reactions to changing conditions will not be decided by some central unit in the network, but decentralised by those units which are primarily affected (e.g., transportation hubs, vehicles or even packages). This decentralised approach implies that the unit which decides its next steps might only have limited knowledge about its environment.

A logistics system based on the above principles allows the transfer of more decision competence from the logistics service provider to autonomous representatives of the individual logistic entities. Furthermore, it creates a new approach to routing problems. Considering packages as autonomous, we may focus on transferring models and routing algorithms from the network layer of communication networks to logistics, cf. Sec. IV.

The decentralised approach yields also the need for exchange of local information with other parties involved in the transportation process. As most of the actors in this logistic process are mobile, the means of communication needs to be mobile radio communication. The communication is required to be cost-efficient in the way that it enables better decisions by providing non-local information, but doing this by using cheap wireless links or reducing the amount of data that is to be transmitted. In Section III the communication technologies involved in these future logistic applications are studied in more detail.

Since January 2004, a German Collaborative Research Center (CRC 637) has been established at the University of Bremen. It is named 'Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations'. The CRC consists of several projects involving the academic disciplines electrical engineering, information technology, mathematics, computer science, production engineering, and economics. The projects can be divided into three areas: Area A is about basics for modeling of autonomous cooperating logistic processes, area B is about methods and tools for these processes and area C (which will be started in a later phase of the CRC) is about applications. The research presented in this paper is funded by the German Research Foundation as part of the subprojects B3 'Mobile Communication Networks and Models' and B1 'Reactive Planning and Control'.

III. COMMUNICATION FOR AUTONOMOUS LOGISTIC PROCESSES

The communication in autonomous logistic processes can be done by using the standard infrastructure networks as described in Sec. III-A and/or based on ad-hoc/sensor networks as shown in Sec. III-B.

The overall system overview is depicted in Fig. 1. The Figure contains the logistical objects that were taken into account, i.e. Packages, Vehicles and Distribution Centers. The

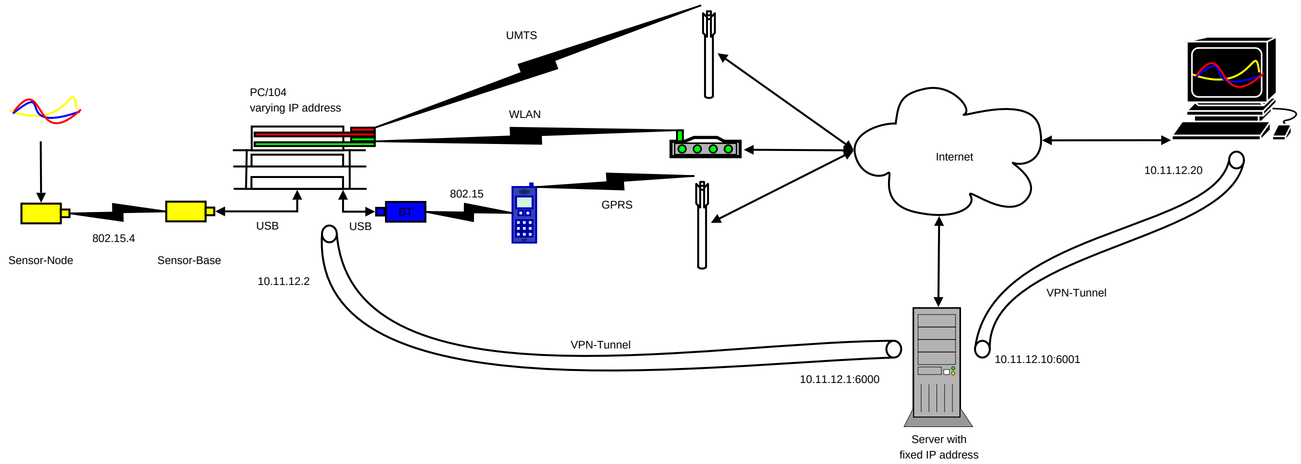


Fig. 2. VPN based mobility solution

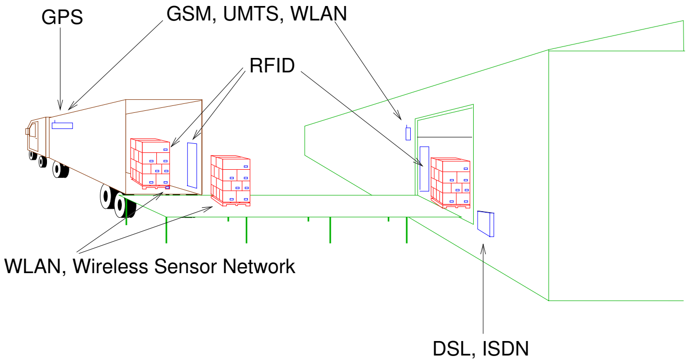


Fig. 1. Communication System Overview

communication systems involved are shown for those logistical objects.

A. *Infrastructure Networks*

The usual infrastructure networks such as *Universal Mobile Telecommunications System* (UMTS), *General Packet Radio Service* (GPRS) or *Wireless Local Area Networks* (WLAN) can be employed for the usage in those future logistic processes. However an adaquate way of choosing the appropriate system, if several systems are available, needs to be put in place. Furthermore, maintaining connections independent of switching between the underlying services in cases of limited availability is required. The mechanism employed by TZI's CRC 637 demonstrator to solve this challenge is to use *Virtual Private Network* (VPN) connections on top of the real network connection.

Fig. 2 depicts the objects that are involved in maintaining the connectivity of the mobile logistic object, which contains the sensor nodes and the communication gateway on the left hand side of the Figure. The right hand side of the figure contains the static or network part of the solution. The communication gateway is based on a compact computer in a format called PC/104. The PC/104 computer is equipped with multiple air interfaces, a UMTS card, a WLAN card and a GPRS mobile attached via Bluetooth. Those wireless technologies are used for creating the network access. When changing the network access technology, the PC/104 initiates a new VPN connection to a server with fixed IP address in the Comnets Testbed. The VPN connection creates a logical interface with private IP range (i.e. `10.11.12.1` and `10.11.12.2`) on the PC/104 and the server with the fixed IP address. The PC/104 routes its traffic along the default route, which is the VPN connection. The VPN connection is re-setup when changing the underlying radio technology. The application that communicates on the PC/104 is not recognising a change in the radio technology. The application running on another machine (i.e. `10.11.12.20`) trying to communicate with the mobile logistic objects' device, is also setting up a VPN connection to the server with the fixed IP address (here `10.11.12.10`) and logical interfaces on both machines will be created. Thus the server with the fixed IP address has two logical interfaces referring to the two VPN connections it has. Between those two interfaces IP routing is setup. The client machine `10.11.12.20`) thus can access the PC/104 using a static IP address.

Other technologies such as Mobile IP could also be applied to solve the problem of addressability from the network. Mobile IP would additionally be able to optimize routes, so that the data traffic would not have to pass the server. The VPN solution however provides encryption, which is left to higher layers in Mobile IP.

B. *Sensor Networks*

The previously mentioned VPN connection enables additionally to connect transparently with regard to the network service to and from the mobile entity, e.g. a vehicle. In the mobile entity a sensor network is set up, based on the standard IEEE 802.15.4, defined in [2]. The sensor network consists of moteiv Telos B motes running the operating system TinyOS as mentioned in [3]. The motes are equipped with humidity, temperature and light sensors. Additionally, the voltage and the chip internal temperature are monitored. This sensor network allows the in-transport monitoring of the goods and enables better decisions based on the goods' condition. The sensor network configures itself dynamically according to the surveillance needs of the goods. This means that, when a good needs to be surveilled with respect to atmosphere gases, it asks for a wireless gas sensor mote to be placed into the vehicle. The sensor will be automatically integrated into the already existing sensor network without the need for a manual setup.

C. Agent Platform

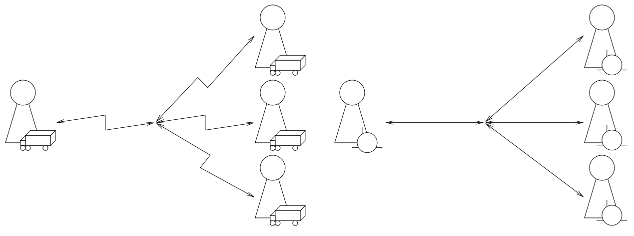
Another integral component of the autonomous logistic process system is the agent platform of the CRC 637. As a generic platform for simulating, evaluating and executing logistic scenarios with logistic entities as autonomous actors an agent-based simulation system has been developed. This system allows for a flexible mapping of logistic entities to software agents and provides logging, evaluation, introspection, visualisation, and interaction features. The platform is designed with the FIPA-compliant Java agent development framework JADE. JADE-LEAP is an extension to JADE that enables the framework to run mobile devices such as PDAs and mobile phones, cf. [4].

JADE additionally supports mobility within the platform. Mobile Agents are agents that have the specific feature of mobility. These software programs can move to the place where the data is, on which they shall do their operations. Depending on the amount of data and on the size of the code, mobile agent technology leads to lower data volume that needs to be transmitted.

The evaluated logistic scenarios can be classified into four different types. Depending on the logistical object represented by the mobile agent, four different combinations of wireless and fixed links are considered.

The topology of a mobile agent, that is representing the intelligence of a vehicle and would like to communicate to other mobile agents of vehicles, is as depicted in Fig. 3(a). This mobile agent requires a wireless connection on the access side as well as on the links to the other vehicles.

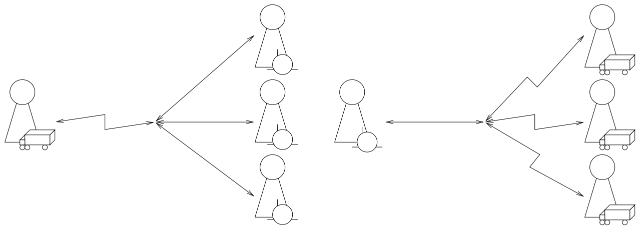
Contrary a mobile agent being a representative of a distribution center that would like to interact with other representatives of distribution centers, has all fixed connections as shown in Fig. 3(b).



(a) Wireless/Wireless (b) Fixed/Fixed

Fig. 3. Common Scenarios

Similarly a vehicle mobile agent communicating with a distribution center agent has a mixed wireless and fixed connection and vice versa. For a distribution center agent interacting with a vehicle agent, see Fig. 4(a) and Fig. 4(b).



(a) Wireless/Fixed (b) Fixed/Wireless

Fig. 4. Mixed Scenarios

The middle point where the connections are split up is assumed to be host of a mobile agent system. Furthermore, an infrastructure network is assumed, so that there is no direct peer-to-peer ad-hoc communication possible. In this mobile agent system, the translation between migration and communication and vice versa is done. When there is communication on the first link and migration on the later links, it is assumed that the mobile agent is already available at the interfacing host.

In Figure 5 the analytically computed network load for a varying number of communication partners (fan out) and the ability of the mobile agent to compress the data, here called selectivity, is depicted. If the selectivity is 0 % no data will be transmitted, if the selectivity is 100 % no compression is performed. The surface marked with 'M/M' denotes network load imposed by migration, the surface marked with 'C/C' gives the network load created by pure communication. It can be seen that for selectivity values below 40 % , the network load of migration is lower than the load of communication. With increasing fan out the migration is getting even more advantageous to communication for good selectivity values. If however the selectivity is bad (>40 %), communication is preferrable over migration, because for migration the code of the agent needs to be transmitted to the remote partner. Mixtures of communication and migration are shown in Figure 6. While the surface marked with 'M/C' is close to the surface marked with 'C/C' in the earlier Figure, the result for 'C/M' is close to the 'M/M' result. 'M/C' means that the first link is done using migration, and the later links are all done using communication.

For the computation of those results, however, it is assumed that the code at the remote partners is not present. Improvements of migration can be used by having a probability that the code is already at the remote location, see also [5]. This assumption holds for a system in which the code is being cached.

IV. DISTRIBUTED ROUTING ALGORITHMS FOR LOGISTICAL NETWORKS

When investigating distributed approaches for decision-making in logistic networks, methods from other technology

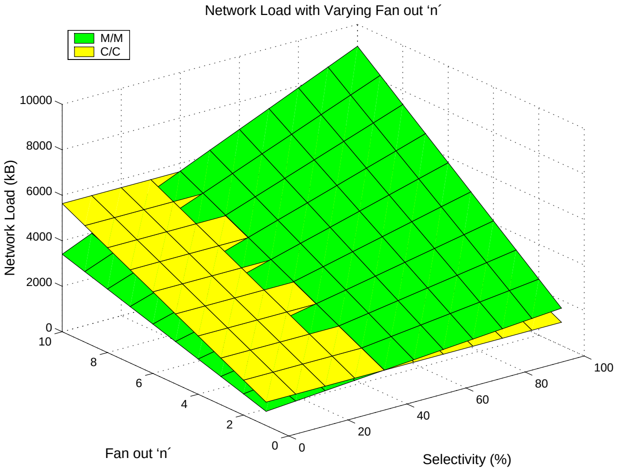


Fig. 5. Network load with varying fan out and selectivity(M/M and C/C)

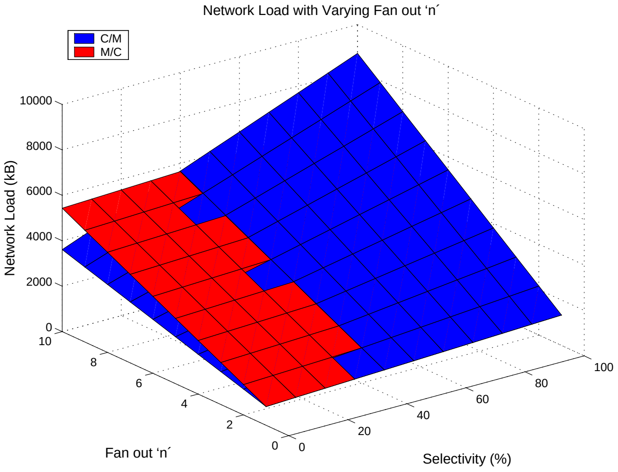


Fig. 6. Network load with varying fan out and selectivity(C/M and M/C)

areas can be examined for their reuse in logistics. One of these technology areas is the area of communication networks. Distributed routing as such has already been successful in communication networks for some decades. Therefore, the routing methods used there are investigated concerning their suitability for distributed routing in transport logistics. The most promising methods are those being used in wireless ad-hoc networks, as they are totally distributed (no central routers are present, every node can act as a router). Furthermore, they are designed to deal with the dynamic changes that can occur in wireless ad-hoc communication.

From ad-hoc routing protocols, it is known that some signaling is needed to have up-to-date routing information where it is required. When these routing concepts are transferred to routing of autonomous logistic objects, these objects will require a corresponding signaling as well. This clarifies why combined research on the logistics and the communication in a scenario is required: Each routing method implies its own specific needs for communication, so the feasibility of the required communication is crucial for the success of the routing approach.

In a scenario where vehicles and packages are autonomous logistic units that are deciding about routes based on their individual knowledge, the decisions have to be made available to others, e.g. the packages should know which vehicles have routes that match their requirements, vehicles have to know which packages are not available for them any more, and so on. This could either be done by direct communication between all the vehicles and the packages or by some kind of "indirect communication". Indirect communication means the vehicles inform an "information broker" about their routes, packages can retrieve the information from there and vice versa. A concept where the (logistic) network nodes act as information brokers so that this brokerage is also distributed is depicted in Fig. 7. This figure shows the importance of communication in such scenarios.

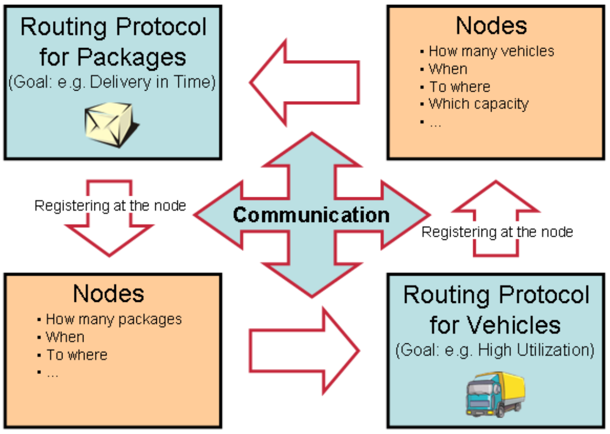


Fig. 7. Distributed Routing Algorithms and Communication

V. SIMULATION

To determine and measure the flexibility of autonomous logistic processes, a discrete event simulation has been set up [6]. This simulation environment simulates the autonomous algorithms as well as the communication of those algorithms. The environment is specific to the interrelated communication and transport problem. It is neither a simulation of just transport nor a simulation of just communication, but an interconnected simulation, where each autonomous logistic object acts on its own and its communication need is recorded.

The DES model is based on a scenario description. This scenario description is composed of several instances of the following transport related components: Vertices, Sources, Sinks, Edges, Vehicles and Packages.

Vertices
are locations in the network with either a possibility of direction change or the possibility for transshipment or both.

Sources
are extensions to vertices, "generating" packages. Details of the generation (package destinations, generation rates) are also specified in the scenario.

Sinks
are vertices to which packages are delivered. Explicit specification of sinks can be omitted as the source details already include implicit definition of sinks.

Edges
are connections between vertices. Edges are considered to be directed.

Vehicles
are transport units moving on the edges and carrying packages.

Packages
are the goods to be transported. A package is considered to be indivisible.

Furthermore, the scenario contains the following communication relevant objects:

CommunicationUnit
is the device enabling the logistic objects to communicate. A logistic object may have multiple CommunicationUnits for different communication networks.

CommunicationUnitManager
manages multiple CommunicationUnits and selects one, according to certain requirements.

MetaCommunicationUnitManager
performs the communication and enables tracking of the amount of communicated data.

A sample scenario consisting of 18 German cities as vertices and the freeways interconnecting them as edges is depicted in Fig. 8.

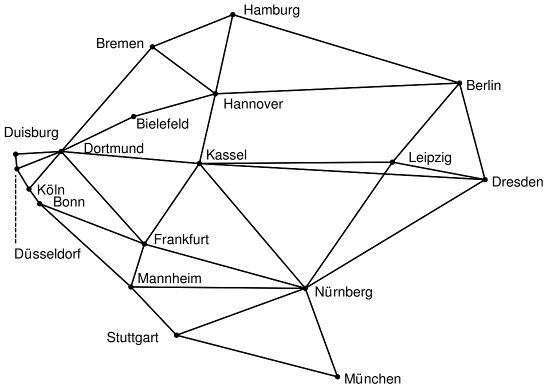


Fig. 8. Sample Scenario for discrete event simulation

Most of the logistic and communication components mentioned here have a serveral attributes, e.g. a vehicle has a capacity, a maximum speed and others. The scenario description is given in XML formatted input files. At the initialisation of a simulation, these input files are parsed and all objects contained in the scenario are created and initialised with the respective attributes.

The output observed in the DES is the packet travel time, utilisation of the vehicles, etc. in the format of histograms and probability density functions. Furthermore, the routes taken by packages and vehicles are recorded. The total amount of data communicated, amount of data per vehicle, per communication system etc. is output with respect to the communication.

VI. CONCLUSIONS AND FURTHER RESEARCH

This paper presents the usage of mobile radio services in future logistic applications. During the course of the paper autonomous logistic processes were presented and their need for communication was shown. The communication can be done using various information and communication technologies, i.e. infrastructure and sensor networks, mobile agents. An analysis of the behaviour of mobile agents has proven that they are a valuable technique to reduce the amount of data that needs to be communicated. One key concept of the autonomous logistic processes are distributed routing algorithms for those logistical networks. To evaluate different routing algorithms and their need for communication a simulation environment has been setup.

Further research will focus on integrating the distributed logistic routing algorithm into the simulation environment. The VPN based hardware demonstrator will be extended with an agent environment, so that the analytically proven solution can be verified against a real implementation.

ACKNOWLEDGEMENT

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