Dynamic routing using the network of car drivers
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ABSTRACT
Since 1995 there is a project called “SmartRoad” running at TUDelft. The goal of the project was to design ICT solutions for traffic control and warning systems. In this paper we focus on dynamic routing systems. The basic idea is that car drivers communicate with each other via an intelligent system implemented on the network of lamppost. By tracking individual car drivers the system gets real time information of traffic speed along the roads. Based on that information dynamic routing algorithm has been designed, which is based on concepts of artificial life. The Ant Based Control (ABC-) routing algorithm computes the shortest traveling time from start to destination. A simulation environment has been implemented and experimental results of static and dynamic routing will be presented in this paper.

Categories and Subject Descriptors
D.3.3 [Programming Languages]: Language Constructs and Features – abstract data types, polymorphism, control structures.

This is just an example, please use the correct category and subject descriptors for your submission. The ACM Computing Classification Scheme:
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Keywords
Dynamic routing, multi agent system, ICT, simulation

1. INTRODUCTION
Nowadays, especially in the Netherlands, the road network is flooded by cars. In the rush hours a total of 200-300 kilometers of traffic jam is reported every day. The direct costs of the delays caused by these queues have been estimated to be about 1.5 billion Euros in 2008, whereas the indirect costs may be even higher. These costs include follow-up costs because of arriving early or late at the destination, and prevention costs of trying to be in time. Consequently, a lot of effort is carried out to solve these traffic problems. Research into automatic car following systems is carried out, which aims to reduce the minimum distance between cars and consequently to increase the capacity of the road network. Teleworking at home is encouraged, to reduce the number of movements each day. Large sums of money are invested in the public transport system and the road network. Simultaneously monitoring systems are placed to track the traffic on the motorway network. Based on that information dynamic routing systems can be designed. A disadvantage is that individual car drivers can not be detected and tracked. An alternative is to track car drivers via their mobile phone. A telephone provider has the identities and is able to track car drivers. At this moment there are dynamic routing systems available based on that data.

Most of the currently available route planners take no dynamic traffic information into account. Considering the very high traffic density on the Dutch road network this is a serious demerit. These so called ‘static planners’ only provide optimal routes when there is no congestion along the planned route. As was stated before, every working day there is an average of at least 200 kilometers of congested road, so these static route planners are only useful during relatively few hours of the day. It would be of great help in planning a trip if the planner could incorporate dynamic traffic information. Not only would such a planner be able to search for another route when there is congestion along the statically planned route, it would also give a realistically estimated travel time.

Tracking systems can provide real time data to fine tune the routing algorithm. But to plan a route in time route planners need not only current traffic speed but also future travel speed. Good predictions of travel speed along the roads are needed. Such predictions can be based on historical data. In our case we logged data along the highways for one year. Based on that data we modeled the travel speed as a function of time. Several models can be designed for different days of the week and changing weather conditions. Models based on historical data can be adapted to real time data.

In this paper we consider a new way of tracking car drivers via the lamppost systems along the roads. Via a wireless device car drivers can connect lamppost and on the connecting lamppost network many software systems can be implemented such as dynamic routing systems but also access to Internet. Our dynamic routing system implemented on the lamppost network is a decentralized system. The question is if local optimal routing results in global optimal routing. But a decentralized system is less vulnerable than a centralized system. A crash of local servers has only local impact. In case of centralized systems a crash of
centralized computers results in a crash of the whole network. Centralized and distributed systems have there advantages and disadvantages. A centralized system has the disadvantage of high communication load and needs a high computational power to compute global routing. Nevertheless we also implemented a dynamic routing system on a central server and use personalized devices to contact the central server via Internet. At this moment there exist many devices to access Internet anytime and anywhere.

For both systems the decentralized and centralized one we developed a Personal Intelligent System (PITA) which is context sensitive and able to support the car driver. The PITA is a handheld device with software systems that provides ubiquitous communication between travelers. This communication consists of travel planning. The PITA system should guide a traveler during his journey from the departure to the destination address. During this journey the traveler should not worry whether he travels along the best route: the PITA guides the traveler completely, also when unforeseen events (accidents) happen. It should be noticed that the best route is the best route with respect to the traveler’s wishes. Most travelers want to travel along the fastest route, but other travelers may want to travel along the cheapest route or less congested routes or may have another interpretation of best route. The PITA will integrate several information services, ranging from the complex task of planning a travel schedule for a future trip to informing the user of transport delays and alternative travel schedules. While traveling, the PITA will provide the traveler with information on transfer points and delays and alternative travel schedules. While traveling, the PITA will signal upcoming transfer points and providing information on transfer routes in the nodes. En route, the PITA will also provide the traveler with information concerning delays, calamities and alternative routes, if applicable.

The outline of this paper is as follows. In the next section we will discuss related work on routings systems, agent networks and. Hen we present information on tracking systems along the highways in the Netherlands and the network of lamppost. Then we will discuss the design of our PITA system. Next we present our simulation environment and finally results of our experiments.

2. Related work
The context-awareness systems are aimed at using the context knowledge to provide the mobile users with access to information and services. The use of context to support individual behavior has recently become an increasingly high potential research topic. In the beginning such systems were mainly restricted to location-aware mobile applications. A list of some previous researches on context-aware systems and applications is presented in (Chen & Kotz, 2000). The elements of the research presented in the current paper have been developed, parallel to some of the previous projects. The Foundation for Intelligent Physical Agents (FIPA) has developed specifications for interoperability among agents and agent-based applications. The Personal Travel Assistance Specifications (PTAS) (PTAS, 2000) provided by FIPA support mobile platforms in travel domain. The context and location awareness define well founded concepts for interfacing with environmental devices and human actors. The operability in smart spaces is based on the interaction with controllable devices such as video conference systems, domestic appliances, cameras or others, by using specific loadable remote controls on the users’ mobile devices (Kalkbrenner & Köppe, 2002). The paper (Bardram & Hansen, 2004) introduces for the first time the concept of context mediated social awareness as a notion to express how context-aware computing can be used to facilitate social awareness and further proposes the AWARE architecture to support context-mediated social awareness. The European MOBILEar system (Lonsdale, Baber, Sharples & Arvanitis, 2003) includes context-awareness technology for supporting the learners using mobile devices. The dialog is based on relevant information to what the user is doing, where and how he/she is doing it and so according to the learner’s goals, situation and resources. Great efforts have been focused toward applying the context-awareness methodology on working spaces to help people to perform optimally. In the case of hospitals, Electronic Patient Records (EPR) have been adapted to communicate with context aware pill containers and context-aware hospital beds that react and adapt to various working contexts (Bardram, 2004). Further on, the AwarePhone system of (Bardram & Hansen, 2004) is designed to support context-mediated social awareness among hospital clinicians. Social-awareness has been used for improving the quality of social interaction and tourist guiding. GUIDE system (Cheverst, Mitchell, Davies & Smith, 2000) offers the visitors of Lancaster city the possibility to interact with a model representing the city via handholds. The physical location of visitors is represented in the information space in order to enable a form of social awareness among the city visitors. The visitors are able to change the information content also by augmenting existing descriptions with their own ratings on the city attractions. The CRUMPET European (Schmidt-Belz, Zipf, Poslad & Laamens, 2003) project applies emerging technologies for offering individualized information and services to heterogeneous tourist population.

The Java Agent DEvelopment framework (JADE) is an implementation of the FIPA standard, implemented in Java (see [BCPR03]). The copyright holder is Telecom Italia Lab (TILAB), but the software can be used free of charge. Specific features are the possibilities for distribution of an agent platform over multiple machines and a set of graphical (debugging) tools. A JADE Main Container is used to host the AMS and DF agents, while other Sub-containers can be added to the platform to create a distributed platform. It is also possible to replicate the Main Container over multiple platforms, to ensure operation after the machine hosting the Main Container crashes. Several add-ons exists for the JADE platform implementation. Most notably are the LEAP add-on, which combined with JADE forms a platform for mobile devices, the Jadex add-on, which makes it possible to design agents based on the Beliefs, Desires and Intentions (BDI) model, and the HTTP MTP add-on, which allows agent communication over the HTTP protocol. The Lightweight Extensible Agent Platform (LEAP) is an extension for JADE, which enables agents to use mobile devices as agent platform (see [LEAP]). Using LEAP we were able to implement the centralized version of our PITA system a platform which is not only distributed over different servers but can even be extended to devices which are connected by a wireless connection.

3. Car tracking systems

3.1 Monica system
queue reports are also used on so-called Dynamic Route central processor are translated into queue reports. These queue At the so called Traffic Information Centers (TIC) the speed, data, stores these data and sends the data to the TIC's. The central processor takes care of the collection of raw detector perform automatic incident detection and to show the right signs. communication falls out the substation runs its own program to send data when this processor asks for them. When incident detection (AID) and communicates with a central processor to send data when this processor asks for them. When communication falls out the substation runs its own program to perform automatic incident detection and to show the right signs. The central processor takes care of the collection of raw detector data, stores these data and sends the data to the TIC’s. At this moment a monitoring system a monitoring system was placed along all major Dutch highways to be able to detect incidents. This system was called MONICA, after MONitoring Casco system. In Figure 1 the MONICA system is illustrated. Major components of the system are the detection stations. Every 500 meters two induction loops have been placed in each lane. The data of these loops are collected by the detection stations, which each have their own microprocessor that processes the data and sends these data to the substations. The substations are placed beneath the signal signs they control. Each substation processes the data of maximal three detection stations to perform automatic incident detection (AID) and communicates with a central processor to send data when this processor asks for them. When communication falls out the substation runs its own program to perform automatic incident detection and to show the right signs. The central processor takes care of the collection of raw detector data, stores these data and sends the data to the TIC’s. At the so called Traffic Information Centers (TIC) the speed, intensity and flow measurements that have been collected by the central processor are translated into queue reports. These queue reports are distributed using radio, Internet, teletext, etc. These queue reports are also used on so-called Dynamic Route Information Panels. Unfortunately there is no Monica system within a city and will not be implemented the coming years. We found an alternative in the lamppost systems. There is also a lamppost system along the highways so her is an opportunity for an integrated system. 3.2 Lamppost system The PITA is an interconnected distributed system that provides its users with an optimal route towards their destination. The routing system consist out of routing service that employs the antbased algorithm, to determine the most time optimal routes through a city in a distributed manner. The PITA consists out of two components an onboard device located in the vehicle of the user, intelligent lampposts spread throughout the city. To facilitate communication with these components the PITA is active on three layers within the city environment as shown in Figure 1. The PITA employs the ether within the city to enable wireless communication between intelligent lampposts, and vehicles while the power-line infrastructure is used to facilitate communication between intelligent lampposts. The city road network dictates the distribution of the intelligent lampposts and thereby the lay-out of the network on the wireless and power-line layer. The effectiveness of the routing solution offered by the PITA depends in large part on the traffic condition data collected by the users concerning the delays they encounter while traveling along a certain road. In order to collect this information the PITA needs to communicate with the vehicles on a frequent basis. The communication between the user and the PITA could be established via different methods such as mobile telephone. The drawbacks of using a mobile telephone to facilitate communication between the PITA and the user are numerous. Rental prices on telephone lines would be substantial, added costs for users would make the PITA less attractive and the amount of information to be transferred between the various components of the PITA would make the system infeasible. The solution we have chosen remedies the drawbacks described above and is highly cost effective. We require that each user of the PITA possesses a navigational device such as TomTom or Navteq. When the user The PITA is an interconnected distributed system that provides its users with an optimal route towards their destination. The routing system consist out of routing service that employs the antbased algorithm, to determine the most time optimal routes through a city in a distributed manner. 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When the user purchases a subscription to the PITA service he receives a small onboard device that is able to interface with his navigational system. This small onboard device contains a wireless transmitter and receiver and a processing unit to interpret and exchange messages with the PITA. Through the interface with the users navigational device the onboard device is able to query the user for information and display driving instructions received from the PITA that lead towards the destination. Communication between the PITA and vehicles occurs every time the vehicle comes into contact with an intelligent lamppost. During these periods the vehicle supplies the intelligent lamppost with traffic condition data gathered by the onboard device by measuring the time between intelligent lampposts. The intelligent lampposts form the backbone of the PITA in that they form the communication structure through which data is collected, transformed into information and distributed to the various components of the PITA. Intelligent lampposts are modified normal lampposts that are placed at each intersection throughout the entire city and near conglomerations of parking places controlled by the PITA. Through their common connection on the cities power-line infrastructure they form a distributed interconnected network that is able to exchange information via power-line communication technology. Each intelligent lamppost further contains a wireless communication device that allows it to The PITA is an interconnected distributed system that provides its users with an optimal route towards their destination. The routing system consist out of routing service that employs the antbased algorithm, to determine the most time optimal routes through a city in a distributed manner. 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Through their common connection on the cities power-line infrastructure they form a distributed interconnected network that is able to exchange information via power-line communication technology. Each intelligent lamppost further contains a wireless communication device that allows it to communicate with vehicles of users and parking place sensors and a small processing unit to process routing information and maintain routing tables. By collecting and exchanging data about current traffic conditions on the road of the city and the usage of the ant-based routing algorithm the intelligent lampposts are able to discover time optimal routes to every destination within the city. This information is then shared with the users of PITA via wireless communication. The interconnected distributed network of intelligent lampposts channels all messages related to the PITA through the power-line infrastructure of the city. The large amount of intelligent lampposts and their limited responsibilities makes the network highly robust against sabotage or failure of one or more intelligent lamppost. While failure an intelligent lamppost will decrease the effectiveness of the routing solution offered it does prevent the PITA from operating as normal.
4. A distributed PITA model

The centralized version of the PITA system is an application running on a handheld device providing communication between users and central server. It provides the user with an up-to-date personalized advice how to reach his destination based on current available information. An important aspect of the PITA system is that it relieves the user of having to find the best route. By determining the position of the user using GPS or other techniques the system is able to optimize the route from the user and update the advice as the user travels and new information becomes available. In order to communicate with different types of users in different kind of situations, the PITA system provides a multimodal interface to the user. This means the communication can be based on speech, icons, text or graphical interface, depending on the preference of the user and the situation the system is used. To optimally fit the desires and demands of the user, the system keeps track of the preference of several users. These preferences can be changed by the user, but the system also tries to learn the user preferences from the day-to-day use.

In order to route the users, the system uses the static information about the environment such as the street plan with the required distances. But advising the users about the best route to his destination requires accurate information about the dynamic changes in the environment and routing algorithm to find the optimal connection between his current location and the destination. Since the position of each user is known at each moment, the system can compute the actual travelling speeds. Another source of information is the observations from the environment provided by the users. The quality of the advice of the PITA system depends of the quality of the user input. All users realize that they have to work together in providing the system with high-quality complete information. Another aspect of the PITA system is that it generates a personal advice. The goal of the PITA system is not to optimize the routing of the whole group of users but the routing of individuals. The users get a tailor made advice instead of a general advice. As handhelds become more and more powerful every day it will be possible to run a large part of the application on the handheld device. Ultimately the application will completely run on the handheld device and depending on the information which is available optimizes the advice for the user. This information can come from the nearby users which are also using the PITA system, for instance by using ad-hoc networking techniques or by using dial-up or UMTS or GPRS-based mobile internet connections to gather the required information about the positions and travelling speeds. The PITA system consists of individual hand-held applications, gathering and exchanging information each-other.

As shown in figure 2, the PITA system has two user interfaces: a management interface and a handheld interface. The management interface is used for viewing and modifying the system configuration. The handheld interface is used by travelers using a handheld device to communicate with the system. A central role is played by the distributed agent platform that runs personal agents for each individual traveler. In order to give an optimal advice to the traveler, the personal agents receive information about the best
route to the destination, given the current delay situation and occurring delays during the trip. Using the user position it is possible to determine whether the user is experiencing a delay. This information about delays is also communicated back to the system itself, to actualize the stored delay information. Assuming that the system receives several delay notifications from users that pass a certain route segment, it may automatically conclude that a possible crisis event i.e. an accident has occurred in the area. Every time a set of observations is available, the system performs a classification of the type of event and the causes that generated that event. For instance, the handheld device components of some users passing a tunnel transparently report delay information to the system. The system automatically tries to determine if the event is a delay event and the cause of the delay and so takes into account a set of crisis-related hypothesis. Each hypothesis may be assessed in a probabilistic way from the knowledge. Further, the state of reasoning process is updated dynamically, according to the new reports coming from users that witness the event (Figure 2). The new observations are assumed to increase or decrease the confidence of any of the hypothesis taken into account. Every hypothesis triggers some scripts, anticipating the future behavior of the user. In case of a bomb explosion specific area will be blocked so that no new users enter the dangerous area. Users in the dangerous area are routed outside.

So users are not only routed to their destination in an optimal way but sometimes the destination is adapted or changed completely. Currently, the reasoning process that works on fusing distinct observations relies on a rule-based system. Specific rules are considered for estimating the correct status of the traffic event. Ongoing work is aimed at enhancing this process with a probabilistic approach based on Bayesian Belief Networks.

The system feedback is given to the users on their hand-held applications (Figure 3). However, there are some cases when more informational media are available. More than that, assuming that the user handheld is out of battery or there is no connection to the local or global ad-hoc network, the system is not able to guide the user by using handheld interface. There may be still possible to reach the user by using other modalities, as mobile phones, road panels or other emergency devices. The research is ongoing for determining the optimal modalities for communication and for finding formatting mechanisms to automatically convert between different media devices. The context-awareness system has information related to each of its users. That is useful for presenting the system response according to user availability and preferences. Further, information related to each user can be used during the process of solving the report ambiguity.

The delay subsystem is responsible for gathering and storing information about traffic jams. Two important sources for this information are the users of the system themselves and a website of ANWB which gives information on actual traveling times. Probably the most important information for the PITA system is the location of the user. This is necessary to be able to give a traveling advice, estimate delays and to get a view on traveler flows. A possibility is to ask the user of the system to specify his position, but there are also automated ways to determine the position. One possibility is to use the Global Positioning System (GPS). Another possibility is to make use of the GSM system. The Global Positioning System consists of 24 satellites around the world which transmit position data. Using a GPS receiver it is possible to receive these signals and determine the position with an accuracy of about 25 meters, using the angle at which the signal is being received from different satellites. Currently many mobile devices and of course routing systems have an imbedded GPS receiver.

The GSM system consists of a very extensive network of antennas. The antennas are distributed according to the demand for mobile communications, which means the density of the antennas increases around cities (to about one antenna every
Each antenna has a unique identification code (cell-id). While the user travels, the mobile phone connects to the nearest GSM antenna, having the strongest signal. Using the cell-ids, it is possible to determine the position of the user coarsely. A disadvantage of the cell-ids is that every mobile operator has its own network of antennas with its own set of identification codes, which means there are 5 networks with different cell-ids in The Netherlands.

5. Experiments

To test our concepts we modeled a part of the Dutch highway network. For this we used the Quintiq software which has an integrated GIS system. The network we built consists of 58 nodes (highway intersections) and 84 bidirectional roads. Each road is characterized by the number of lanes and the maximum allowed speed. Some of the real roads are composed of multiple segments with different speed limits and number of lanes. In this cases we choose an average speed limit and a fixed number of lanes. For historical data we used data collected from the ANWB website. Because of the big amount of data, we focused only on the morning period between 5:00 and 12:00. In all the nodes we created routing tables for every 5 min interval. We populated the roads with random traffic generated between the intersections. We used two types of vehicles. Half of them were guided using the ABC dynamic routing and the others were routed along the shortest paths computed once with the Dijkstra’s algorithm. For each of the 3306 possible routes we compared the average traveling time between the two types of vehicles with the departure in the same time interval. Our first question was if the dynamic routing makes sense in general case and not only when accidents happen. In the Netherlands at rush ours almost all the roads show delays and the possible alternatives to a route might also be congested. In Figure 5 we display the results. For almost 57% of the routes, faster alternatives were found by the routing system. From these, 3.14% showed an insignificant improvement of less than one minute. 26.23% of the dynamic routes were up to 5 minutes faster than the static ones. A difference from 5 to 10 minutes was noticed in 14.13% of cases and from 10 to 20 minutes in 12.16% of the situations. For 1.3% of the routes the difference was up to 30 minutes. If we consider that The Netherlands is a small country and most of the selected routes are shorter than 150 km, using the dynamic routing system is a real benefit.

Let’s focus now on a particular case. The A2 motorway, which connects two cities in the Netherlands Eindhoven to Amsterdam, is the most congested corridor in The Netherlands. So we selected for a detailed discussion the route between the junctions De Hoght, situated at west of Eindhoven, and Muiderberg, positioned at east of Amsterdam. In Figure 6 is shown for both the static and dynamic routes, how the traveling time between these two locations has been oscillating during the morning.

In our second experiment we tested dynamic versus static routing in a lamppost environment. First we designed a simulation of such an environment as displayed in Fig….

The city environment can be distinguished from the smaller environments through the fact that traffic volumes are reasonable high and remain high for almost the entire duration of the day.
sometimes stretching well into the evening. The city environment for this experiment is modeled after the Dutch city of Apeldoorn that has a ring road along its periphery. A further characteristic is the presence of multiple distinct neighborhoods within the city and the clustering of commercial activity within a certain neighborhood of the city. The ring road allows vehicles to move at an increased maximum speed of 80 km/h giving vehicles the opportunity to travel quickly from one side of the city to another. This prevents overcrowding of the roads within the inner city that have a lower maximum speed. While such a ring road has certain benefits, it can also be the source of congestions within a city.

In the first simulation the static Dijkstra’s routing algorithm has been employed, in the second to the fifth simulation the dynamic ABC algorithm, which can either be Dijkstra’s algorithm or the ant based algorithm. In simulation experiments 2-5 we assume that 20%, 40%, 60%, 80% of the cardrivers used the ABC algorithm. In Fig … we see that the traveling time is decreasing, the more cars using dynamic routing. Each experiment involved 7500 vehicles.

### Figure 9. Travel time if 0-20-40-60-80% ABC routed cars.

#### 6. Conclusions

In this paper we report about recent results of researchers involved in the Smart road project running at Delft University of Technology. The focus of the project is on routing and traffic control. Individual cars want to be routed. To get the dynamic traffic information individual car drivers allow the system to track them. We introduced a new car tracking system based on the lampost network along the roads. A special handheld device, has been designed, called PITA (Personal intelligent Traffic Assistant). The system has been tested on real traffic data and in simulated environment. The results of our experiments show that dynamic routing can improve the traffic flow significant. Next future we plan to use real life experiments.

The new system offers opportunities to offer new services to car drivers. At this moment a system for parking service has been developed. Car drivers entering a city are able to contact the system to reserve a parking place as close as possible to their destination and they will be routed via a dynamic routing systems. The key facto in such a system is our designed PITA system. The results of the parking system are reported in a Journal paper and is currently under review.

#### 7. References


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