AUTO-SENSING AND DISTRIBUTION OF TRAFFIC INFORMATION IN VEHICULAR AD HOC NETWORKS

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Abstract: Established traffic information systems have a highly centralized structure. Numerous roadside sensors deliver traffic data to a central unit where the information is processed. The traffic information is then transmitted, with a significant delay, to drivers via broadcast or on demand via cellular phone.

Within the Traffimatics project, an open telematics communication platform based on vehicular ad hoc networks is developed. By utilizing existing capabilities of vehicles, such as CAN bus and the global positioning system (GPS), the vehicular ad hoc network acts as an intelligent sensor and forms a powerful traffic information system. Vehicles take part in collaborative signal and information processing via wireless links, allowing global information to be reconstructed from locally observed data. The platform can be rapidly deployed, is self organizing and eliminates the need for much of the expensive infrastructure that is required in existing traffic and travel information systems.

1. INTRODUCTION

Vehicles are considered a prime area for the deployment of ad hoc networks and several projects are currently investigating a number of application areas, including traffic and travel information systems. The approach we present here is novel in its use of collaborative signal and information processing to enable observed and predicted traffic information to be distributed in an intelligent manner. This paper outlines a method for the auto-sensing of traffic information using collaborative reasoning within the ad hoc network developed as part of the Traffimatics platform. The paper goes on to discuss an application specific scheme for information distribution for use in vehicular ad hoc networks.

The drive towards in-car information and entertainment systems (telematics), which will enable cooperative vehicle and safety applications, electronic toll collection and in-car Internet access is slowly picking up steam. This together with rapid developments in wireless access technologies (including WiFi), creates the possibility of large-scale ubiquitous computing applications for travelers, including real-time traffic monitoring, dynamic navigation, route weather forecast and location based applications to name a few.

The Traffimatics project aims at investigating the possibilities of using vehicles to create a large-scale self-organizing sensor and communication network enabling travel, traffic, safety and entertainment applications. To achieve its objectives Traffimatics will develop a telematics platform that,

- is cost effective
- integrates seamlessly with other (ubiquitous) computing environments and emerging infrastructure
- adds value to the telematics end-user
- is self-managing requiring no driver involvement
- will easily evolve with technology and end-user demand
- will provide improved traffic and road monitoring
- does not require any driver involvement

As part of this platform, a traffic information system will be implemented on ad hoc networks. A (mobile) ad hoc network is a distributed, mobile, wireless, multi-hop network that can operate without the need for any existing infrastructure [Freebersyser and Leiner, 2001]. Vehicles provide an ideal platform for the deployment of ad hoc networks – they are capable of providing the power necessary for wireless communications and can bare easily the weight of additional communication equipment. Vehicles already have many of the capabilities required by ad hoc nodes such as on-board processors and memory, and other desirable features such as the global positioning system (GPS) and a variety of sensors.

Within an ad hoc network, although each node (vehicle) is an independent device, by coordinating their sensing, processing and communication to acquire information about their environment, it is possible to accomplish high level tasks [Pottie and Kaiser, 2000]. This collaboration makes nodes more autonomous and as a whole, forms a novel type of distributed sensor network. The Intelligent

Transportation System (ITS) presented here goes beyond the capabilities of both centralized systems and existing ad hoc implementations by utilizing the collaborative processing capabilities of the sensor network formed by the vehicles.

The paper is organized as follows: Section 2 gives an overview of related projects investigating traffic information applications deployed on vehicular ad hoc networks. In Section 3 we briefly describe the network architecture and detail the method of auto-sensing within the network. The paper goes on to outline the scheme for distribution of traffic information. Finally, Section 4 offers some conclusions on the methods developed in the paper.

2. RELATED WORK

The FleetNet project develops a communication platform for inter-vehicle communication following the ad hoc networking paradigm [Hartenstein et al, 2001][FleetNet]. In [Lochert et al, 2003] a position-based routing protocol for vehicular ad hoc networks deployed in city environments is investigated as a suitable network architecture for dealing with high mobility. The project aims to develop a range of decentralized floating car data services for deployment on this platform. One suggested application, a self-organizing traffic information system, is presented in [Wischhof et al, 2003]. Within the self-organizing traffic information system (SOTIS), each car broadcasts data such as position and velocity. As another car receives this information, it is compared with a 'Knowledge Base' (unique to each vehicle) to establish whether the information is more accurate/up-to-date than existing information, if so the 'Knowledge Base' is updated accordingly. Entries in the 'Knowledge Base' are associated with geographic coordinates and are combined with a digital 'local map' and displayed as warnings/indicators on an in-car display. No collaborative processing of information takes place between vehicles and there is no attempt to identify abstract traffic events by interpreting sensor data. A design assumption is made that, in general, the relevance and required precision of traffic information about the conditions at a specific location will decrease with increasing distance. The information sent by each node varies according to this distance and the time elapsed since entries in the 'Knowledge Base' were reported.

CarNet is an application for large-scale mobile ad hoc networks, to be implemented as part of the Grid [Liao et al, 2000] project. The Grid infrastructure is an ad hoc network that uses geographical (or position-based) routing and a scalable distributed geographical location service (GLS). Data is communicated between distant nodes in a multi-hop fashion. Data packets contain the geographical location of the destination node, obtained from the location service. Each node communicates only with its direct neighbors where a purely local decision is made to forward packets received to the neighbor that is geographically closest to the destination contained in the packet header. This routing scheme is designed to avoid network flooding, allowing the ad hoc network to scale up to possibly hundreds of thousands of nodes. CarNet aims to support IP connectivity as well as a number of applications, including traffic congestion monitoring [Morris et al, 2000]. Cars exchange speed and location information which are then assembled and overlaid on a local map to provide picture of picture of which routes are congested. The process by which transmitted information is assembled and interpreted as congestion information is not specified. No details of the mechanisms by which the congestion information is propagated throughout the network are given.

3. SYSTEM DESCRIPTION

In existing ad hoc Intelligent Transportation System (ITS) implementations, traffic information is obtained from sensor data transmitted by individual vehicles. However, for traffic information applications, the phenomenon of interest is unlikely to be adequately described by sensor data that may be observed by an individual node. Indeed in existing (non ad hoc) ITS, the information to be extracted is more discrete and abstract, and may be used to answer high-level queries about the 'world state' or to make strategic decisions about actions to take. The ad hoc ITS presented here will seek to provide this information through in-network collaboration. Furthermore, this information will be distributed in a manner consistent with the objectives of the ITS i.e., traffic information will be provided in those areas where it is most relevant. We assume that traffic information is most relevant when a vehicle is in close proximity to its source and when the vehicle has a high probability of entering into proximity. Before we describe these processes, we outline the architecture onto which the system will be deployed.

3.1 Network Architecture

The ad hoc network will comprise two node types: mobile nodes (vehicles) and fixed nodes deployed at the roadside. The number of fixed nodes in the network will be small relative to the number of mobile nodes. A subset of these fixed nodes will be connected to external networks. Each vehicle participating in the ITS will be equipped with a telematics platform interfaced to on-board systems through a CAN bus. Through this platform data will be collected and analyzed from on-board sensors. These sensors may include,

- Anti-Lock Braking System (ABS)
- Automatic Traction Control (ATC)

- Speedometer
- Airbag and crash sensors.

It is assumed that vehicles are able to obtain positional information from on-board GPS receivers. All nodes are equipped with a processor, memory and digital communication equipment.

Nodes organize themselves into a number of local ad hoc networks (or clusters). At this local level, a pro-active routing scheme is adopted so that communication between nodes in the same cluster is responsive. Nodes advertise their presence to their immediate neighbors by transmitting periodic beacons. These beacons are essentially empty packets with information contained only in the packet header. Information contained in the packet header is summarized in Table 1; positional information is included in the packet header to aid information distribution – this process is described in section 3.3.

Field Name	*Description*
Node ID	Unique identifier.
Time-stamp	Time packet was transmitted.
Destination	ID of destination node
Location	Geographical location of originating node.
Velocity	Velocity of originating node.
Heading	Navigational heading of node.

Table 1. Summary of packet header

On receipt of a beacon message, the ‘node id’ of the originating node is added to a list of neighbors. Nodes regularly scan this list to determine link-states. If no beacon message is received from a node in the list, after a given period of time the neighbor is considered lost. This process enables link-state information to be constructed and maintained for the local ad hoc network.

3.2 Collaborative Signal and Information Processing

Collaborative signal and information processing (CSIP) [Kumar et al, 2002] provides the data representation and control mechanisms to allow nodes in the ad hoc network to collaboratively process and store sensor information, respond to external events and report results [Liu et al, 2002]. The process described here is similar in principal to directed diffusion [Intanagonwiwat et al, 2000], a communication paradigm for sensor networks.

Traffic information is generated in the network by means of task requests. Task requests may be issued by individual nodes or they may be 'injected' into the network through a fixed node with a connection to an external network. Task requests are divided into types with each relating to some well-known traffic phenomenon, for instance one task request may be to detect “ice on the road”. Each task request type is associated with one or more of the available on-board sensors which may be sampled to determine the existence of the phenomenon. Taking the “ice on the road” task request as an example, it may be associated with the ABS, ATC and an external thermometer. Particular readings from each of these sensors can be interpreted to indicate that there is “ice on the road”. Furthermore, by setting ranges for each of these sensor readings and combining them, phenomenon can be detected within certain confidence levels.

When a sensing task is generated, it is added to the task list of the originating node. Each entry in the task list contains a number of name-value pairs. A summary of the fields is given in Table 2.

Field Name	*Description*
Task ID	Unique identifier.
Task type	Description of sensing task.
Time-stamp	Time task request was made.
Expiration	Time task request should be discarded
Priority	Priority associated with task request.
Origin	ID of node which issued task request.

Table 2. Summary of Task Request message

The node then transmits the task request to its immediate neighbors. On receipt of the task request, the receiving node checks if there is a corresponding entry in its own task list. If a task request of equal priority and of the same origin is not found in the task list, the new task request is added. The node then directs its subsystems to begin sampling each of the on-board sensors that has indicated by the type of the task request. Samples are then compared with the ranges specified and combined to determine if the event type given in the task request is also occurring at that location. These results are summarized in a task response message and transmitted to the node identified as the origin of the task request. A summary of the fields included in the task result message is given in Table 3.

Field Name	*Description*
Task ID	Unique identifier.
Time-stamp	Time task response was made.
Confidence	Confidence level of generated result.
Origin	ID of node which issued task response.
Location	Coordinates at which response was generated.

Table 3. Summary of Task Response message

Nodes may also forward task requests to a subset of its own neighbors, depending on the priority of the original request and the task result generated at that node. When task requests are forwarded, the forwarding node adds their own ‘node ID’ to the task request i.e., they become the originator of that task request. This process enables task requests to propagate through the network. If an individual node's task list grows too large, task requests with the lowest priorities are removed. Any task request which has expired will also be removed.

As task responses are generated, they will propagate back to the originator of the task request. This node will have a number of responses associated with a single request. These responses are then combined to localize traffic phenomenon i.e., the locations of responses giving high confidence levels can be used to produce a boundary for the traffic phenomenon detailed in the original request. The task response message at the originating node may then be distributed.

3.3 Information Distribution

Traffic information is most likely to influence drivers' decisions when it relates to the immediate area or when they are likely to enter into that area. To maximize information gain in the network whilst keeping the consumption of network resources to a minimum, traffic information (i.e., task response messages) will only be transmitted to a node if that information is relevant in terms of the nodes likely route. The process of information distribution takes advantage of the periodic communication that takes place between nodes in the local ad hoc networks as part of the neighbor discovery protocol.

Consider the scenario shown in Figure 1; at time t_1, a node belongs to cluster 1 and is involved in CSIP to detect a particular event in the traffic network and a task response message is generated. The node's heading changes and the links to nodes in cluster 1 are destroyed. Later, at time t_2, the node comes into communication range of a second cluster.

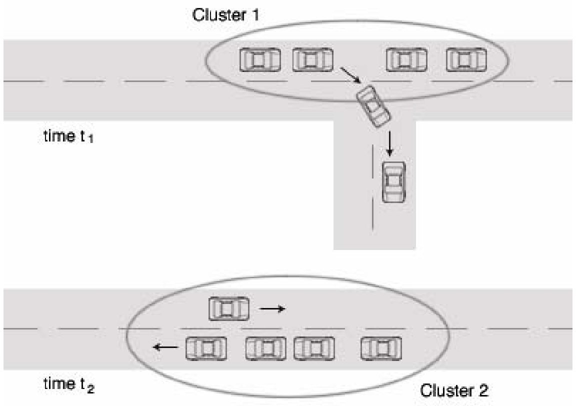

Figure 1. A Task Response message is stored in a mobile node and distributed to another ad hoc cluster.

Links between the node and others in the local ad hoc network are established through the neighbor discovery protocol outlined in section 3.1. As new neighbors are discovered, the node receives beacon messages with positional information included in the packet headers (see Table 1). This positional information is combined with information about the structure of the road network (e.g., a digital map) to determine the likely route of each neighbor. Using this information, the receiving node examines the list of task response messages for any that relate to possible routes of each neighbor. Relevant traffic information is transmitted to that neighbor.

This method of information distribution is novel in that the movement patters of a node are used to determine when it should be provided with traffic information. We anticipate that this method will reduce bandwidth consumption whilst increasing information gain, outweighing any cost associated with the additional processing necessary.

4. CONCLUSIONS

In this paper we present the logical framework auto-sensing of traffic information in vehicular ad hoc networks. This approach recognizes that the information of interest in an Intelligent Transportation System is more abstract or symbolic than information that can be sensed by any individual node. Collaborative Signal and Information Processing is utilized to allow this higher level information to be generated by collaboration between nodes.

The paper goes on to present a novel scheme for the distribution of traffic information. This scheme is application specific and requires some knowledge of the topology of the road network. At this stage we have assumed this information can be obtained from a digital map. It may be possible to infer these 'local maps' from observing transmitted packets and vehicle movement patterns [Lochert et al, 2003]. The scheme is intended to maximize information gain whilst recognizing the bandwidth constraints associated with ad hoc networks.

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