A REAL-TIME TRAFFIC INFORMATION SYSTEM FOR VEHICLE NAVIGATION

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ABSTRACT

The smart use of available radio resources can be used to provide vehicles with real-time on-demand traffic information in a power and cost effective manner. Processing this information to offer route guidance minimizing the total fuel consumption increases the energy efficiency of a car ride. Such traveler information system is not only environmentally friendly; it also gets us a step closer to the Cognitive Radio paradigm, where efficient use of the radio resources meets user demands. This paper proposes an Advanced Traveler Information System (ATIS) that provides vehicles with user specific, on-demand route guidance based on real-time traffic information. Smart use of power and available spectrum, a query strategy that reduces the probability of overloading the system, reliability issues and timing constrains make the realization of the system very challenging. A small scale demonstrator based on cheap technologies such as sensor networks, ISM-band communication systems, and standard equipment for the on-board and central management units has been built in order to provide proof-of-concept.

1. INTRODUCTION

Traffic congestions have enormous personal, financial, safety, and environmental consequences. The delays and inconvenience caused by traffic jams deteriorate the quality-of-life of people sitting in never ending car lines (personal), cause money losses to business owners waiting for goods deliveries (financial), can prevent first responders from accessing the scene of an emergency (safety) and have a detrimental effect on the environment due to the extra emission of air pollutants (environmental) [1].

Nevertheless, traffic congestions can be palliated if information about traffic flow and statistics are known beforehand. Intelligent Transportation Systems (ITS) take advantage of advanced sensor, computer, electronics, and communications technologies and management strategies in an integrated manner [1, 2, 3, 4]. Thus, ITS allow to increase the safety and efficiency of the surface transportation system as defined in [1]. The problem of traffic conditions awareness has been partially mitigated with commercial radio broadcasts [5], traffic reports on the internet [6, 7], and en route traffic displays and/or traffic signals which adapt to traffic conditions [1, 8, 9]. Some of the already available Systems provide even user specific traffic information on-demand [10, 11].

This paper proposes a technique to automatically provide drivers with real-time on-demand route guidance based on real-time fine-grain traffic information over the area of deployment of the system. The proposed technique could enhance already available Advanced Traveler Information Systems (ATIS) by automatically incorporating the traffic conditions as a parameter in the best path calculation of the navigation system. Hence, the proposed system makes use of available infrastructure, sensing, and communications technology in order to provide service subscribers with the information that will get them to their destination in a quicker and more environmentally friendly way by only upgrading the software of the user equipment. A small scale demonstrator based on cheap technologies has been built in order to provide proof-of-concept. The proposed system focuses on gathering traffic information that is used to provide service subscribers with on-demand real-time and efficient route guidance relevant to their needs. In the implemented demonstrator, a sensor network is deployed along the road infrastructure in order to monitor the traffic over the area of coverage providing real-time fine-grain average velocity information. This information is processed in order to provide the required route guidance to the service subscribers.

As opposed to this user oriented approach, other projects under development [12, 13, 7, 14] focus mainly on safety issues. Other traffic monitoring systems place the sensors in the vehicles. This is the case of the CarTel project [15], which relies on opportunistic wireless to communicate the sensed data with a central portal. The communications scheme of other systems such as TrafficView [11] or Fleenet [16] rely on car-to-car ad-hoc networks. The value of such systems is undoubtedly high in terms of safety since they provide dynamic local traffic information. These systems are designed to assess traffic and road conditions in the close vicinity of a vehicle. Hence, their usefulness in providing an effective route guidance between a departure and destination point that are relatively far apart is limited by the short ranged nature of the traffic information they process.

Present commercial navigation systems provide the best path between the present position and the destination but rely mostly on static information. Their awareness of traffic conditions is at best partial and normally not existent at all [17, 18, 19]. Other commercial systems such as DASH [20], calculate the estimated time of arrival of different proposed routes using dynamic traffic information based on GPS measurements carried out by certain cars used as probes and third party information. A similar approach where GPS-equipped mobile phones are used to transmit data to the monitoring system has been adopted by the Mobile Millennium Project developed under the PATH framework [4, 21]. These systems, if adopted massively, have the potential of providing enough coverage so as to provide comprehensive real-time traffic information. Rather than competing with the above mentioned ATIS or navigation systems, the capabilities of our proposed ATIS complements them. We have demonstrated an end-to-end solution where fine-grain real-time traffic information gathering using a sensor network, data communication over a WLAN link, and data processing in both and embedded system and a computer, lead to a navigation decision making process that reflects accurately the present traffic conditions over the area covered by the deployed system.

2. SYSTEM GOAL

The goal of the proposed Advanced Traveler Information System (ATIS) is providing vehicles with user specific, on-demand route guidance based on real-time traffic information. This service, provided over a wireless link, efficiently uses the available sensing infrastructures and radio communications resources in a cost effective and automated manner. The proposed ATIS takes into account the real-time average velocity of each road segment in the best path calculation algorithm that provides route guidance to the service subscribers.

3. SYSTEM OVERVIEW

Figure 1 illustrates some of the different connectivity and data gathering and processing options that could be supported by the proposed ATIS. The modularity of the system makes it both extremely flexible and scalable.

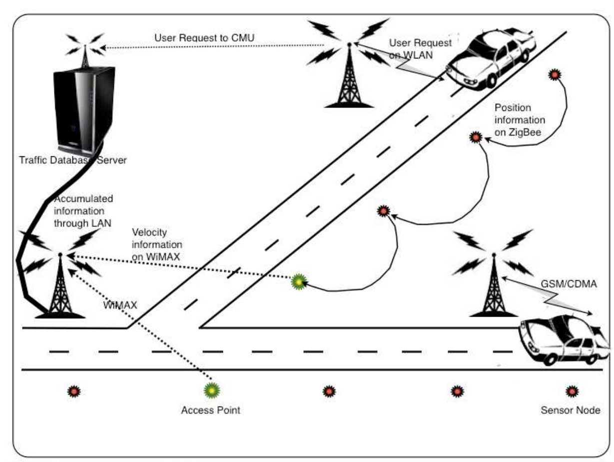

Figure 1. Different connectivity and data gathering and processing options for the ATIS.

Figure 2 shows an abstracted view of the system architecture of the demonstrator [27]. This demonstrator is a scaled down version of the proposed ATIS and shows how route guidance based on real-time traffic conditions can be performed. It comprises all the levels of an ATIS from data gathering to user guidance.

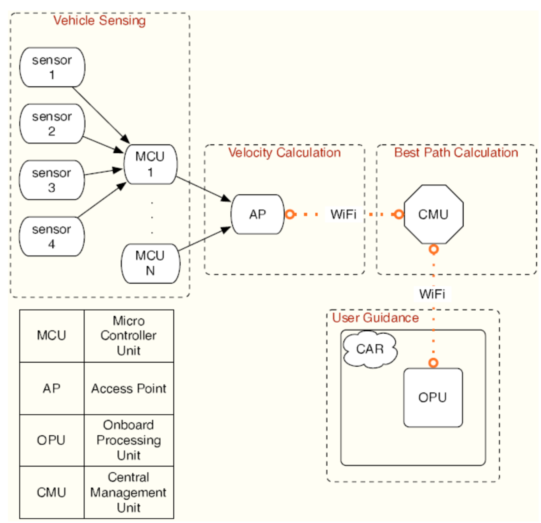

Figure 2. Abstracted block diagram of the proposed ATIS implemented in the demonstrator.

The main tasks performed by the proposed ATIS demonstrator are:
• Vehicle Sensing.
• Velocity Calculation.
• Best Path Calculation.
• User guidance.
These operations are supported by:
• Communication between the different subsystems.
• Database maintenance and accessing.

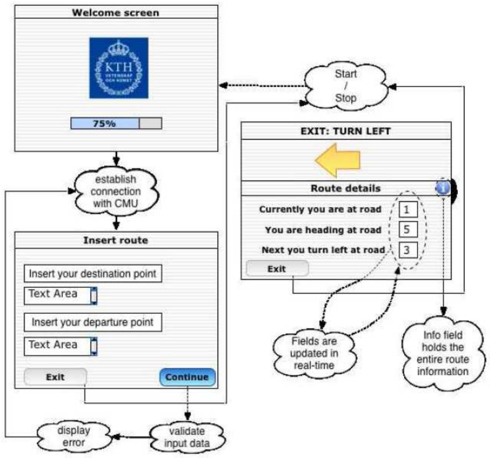

Figure 3. Graphical User Interface (GUI) of the proposed ATIS implemented in the demonstrator.

The user is guided at all times between its departure and destination points. Figure 3 shows a snapshot of the Graphical User Interface (GUI) that was implemented for the demonstrator. In order to test the system a demonstration track was built for the RC cars. Numerical identifiers were associated to the road segments that were monitored in the test track. The departure and destination points were input to the system using their road identifiers. The system provided constant route guidance indicating which road segment had to be taken at each intersection using both the road identifier and an arrow that indicated the direction to take at each intersection.

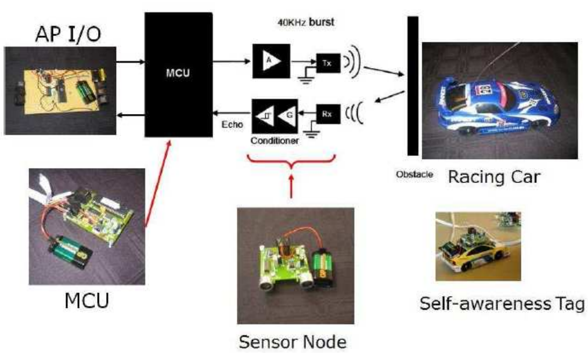

Figure 4. Picture of the demonstrator of the proposed ATIS.

Figure 4 shows a picture of parts of the demonstrator that was built in order to provide proof-of-concept, where RC cars were used to simulate different traffic conditions.

4. VEHICLE SENSING

Processing the information collected by the vehicle sensing units allows to determine traffic density and average velocity in each road segment. A sensor network is responsible for the traffic information detection and gathering. A set of sensor nodes is placed along the length of the roads for position and velocity determination. Figure 5 shows the basic architecture of the sensor network these nodes belong to. Alternatively, other technologies such as GPS or the processed data coming from traffic monitoring cameras or radars could and should be used depending on the characteristics of the area to be monitored [1, 4, 6, 7, 8, 10, 20, 21, 22]. For instance, in an up-scaled version of the system, setting up and maintaining a sensor network would not make sense in a road with low density of traffic in the middle of an underpopulated area. In that scenario, relaying data from GPS readouts to the access points via GSM for instance as in [4, 20, 21] would make more sense. The modularity of the system, depicted in Figure 2 allows to implement each of the system functions (vehicle sensing, velocity calculation, etc.) in different technologies for different parts of the coverage area, be it a newly deployed state-of-the-art system or legacy monitoring systems already available in the infrastructure.

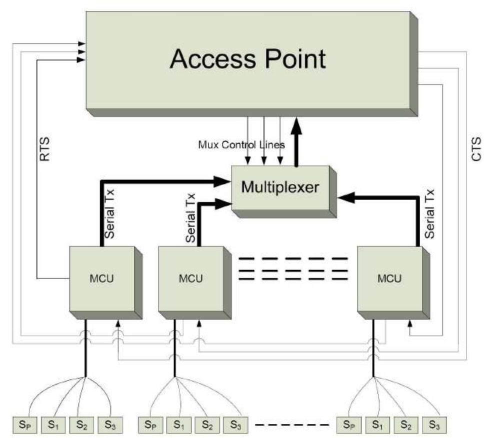

Figure 5. Block diagram of the sensor network deployed in the demonstrator.

4.1. Sensor Nodes

Each sensor node is equipped with a pair of 40 kHz UTT/R4016 ultrasonic transducers [30, 31] that take care of the vehicle detection. In order to detect the presence of a vehicle, a 40 kHz UTT4016 [30] ultrasonic transducer transmits a 40 kHz burst as shown in Figure 6. When a vehicle crosses the beam produced by the ultrasonic transmitter, the reflection of the burst produces an echo that is detected by the receiver transducer UTR4016 [30].

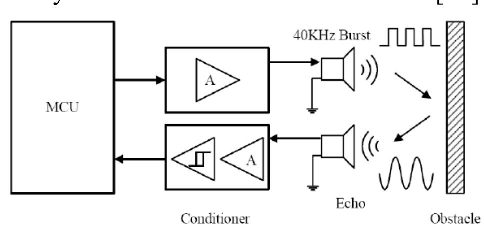

Figure 6. Operation theory of an ultrasonic motion detection sensor.

4.2. Sensor Network

The sensor network used in the demonstrator is built in a hierarchical way. A microcontroller (ATMEGA162 from the Atmel AVR series [32]) based embedded system is used at both levels of the sensor network shown in Figure 5.

In the first level of the hierarchy, clusters of four sensor nodes are connected to a Micro Controller Unit (MCU) each. These processing units control the sensor nodes, pre-process the information they provide, and communicate it to the next level. In these sensor clusters, one sensor node provides position-awareness to the vehicles that are subscribed to the service. Position-awareness sensors allow to monitor the present position of these vehicles. This information is used when calculating the best route to their destination. The other three nodes are used for average velocity calculation along a road segment.

The processing unit connected to each sensor cluster, the MCU, contains a microcontroller that provides the following functionality:

- Generation of the 40 kHz signal to be transmitted by the ultrasonic transmitter.
- Reception of the signal received by the ultrasonic sensors and conditioned by the front-end analog electronics. Each sensor node is connected to a different interrupt port to communicate this information to the processing unit.
- Processing the timing information related to the events that occur on the road.
- Sending the processed information to the access point.

The most important task carried out by the MCU is registering a time stamp every time a vehicles passes across a sensor node. A process inside the microcontroller implements the Finite State Machine (FSM) that registers this time stamp, monitors the car while it crosses the sensor's detection range, and transmits it to the access point [27, 33]. A built-in glitch avoidance mechanism protects the system from environmental disturbances that might trigger the sensor leading to misleading information. Preferably, the link between an MCU and the access point would be wireless, possibly using WLAN (IEEE 802.11a/b/g), or 802.15.4 ZigBee. However, for the purpose of a budget-constrained demonstration a wired link was implemented. In order to provide some degree of fault tolerance, the MCU employs a triple redundancy scheme in its transmission [34]. However, in an up-scaled version of our system, a modern packet protection technique is recommended. As soon as the access point starts receiving data from an MCU, it forwards that bit stream to the main processing unit of the access point through an RS-232 interface [35].

5. VELOCITY CALCULATION

The velocity of each road segment is used as a parameter in the cost function used in the best path calculations. These velocities are computed at the access points using the data coming from the different clusters' MCUs. A number of sensors records the time of arrival of vehicles at different points on the same road where the distances between the sensor nodes are known. In order to obtain a reliable estimation of the average velocity at each road, the measured average velocity is processed by a Kalman filter. Thus, the final estimate is a weighted average of the last measured average velocity and the past estimates. Thanks to this processing of the raw measured average velocities the impact of measurement errors can be reduced.

Local traffic information is relayed from the access points to a Central Management Unit (CMU) for further processing. The data sink nodes queue their channel requests with the CMU and are serviced through a FIFO buffer. The demonstrator system has been sized in such a way that all requests related to a sensor node can be handled before the vehicles reach the next sensor node. As the updates are handled instantaneously, the demonstrator is real time. For large scale implementations, a ZigBee based wireless sensor network is envisaged where, for sufficiently low node densities and a small number of hops to the data sink node, the average delay is often an acceptable system parameter [28].

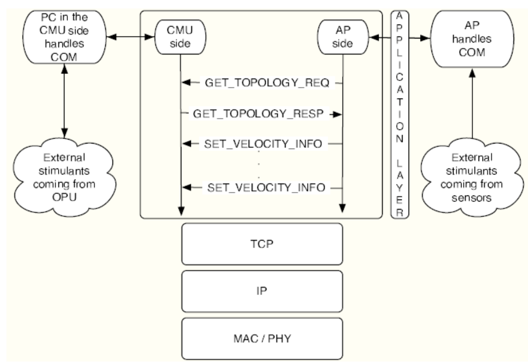

Figure 7. Communication between the MCU and the access point.

The access point needs prior knowledge of the road area it monitors. This topology information is dynamically acquired from the CMU in the implemented demonstrator, as shown in Figure 7. Thus, new access points can be added to the system in real time providing enhanced expandability. The communication between the access point and the CMU is TCP driven so as to exploit its reliable data delivery capabilities. Once the access point has established communication with the CMU and the road topology information has been exchanged, the access point starts sending the velocity updates on its associated road segments to the CMU.

6. BEST PATH CALCULATION

The CMU is responsible for calculating the best route between two points taking into account both the traffic situation and the user preferences.

The supporting tasks performed by the CMU are:

• Generation and maintenance of a road topology and associated traffic information database.

• Communication with the road-side infrastructure.

• Communication with the on-board processing unit of the service subscribers.

The CMU maintains the road topology as a directed graph G := (V,E) where each vertex V_i of the graph G represents a different road segment of the monitoring area. A weight ω_i is associated with each vertex V_i of the graph. The value of ω_i is a function of different parameters depending on the objective function, which set by the user preferences, as:

• Minimum fuel consumption: $\omega_i = f(d, v, L)$.

• Minimum time: $\omega_i = f(d, v)$.

• Minimum distance $\omega_i = f(d)$.

where d is the road length, v the average velocity of the road segment, received from the access points, and L the fuel consumption per 100 km of the vehicle in liters.

The best path that exist between a pair of vertexes $V_{i,j}$ within the weighted graph G is calculated using Dijkstra's algorithm [36]. Dijkstra's algorithm was chosen due to its simplicity and fast convergence when operated on graphs with small set of vertexes, as was the case in our demonstrator. The main risk related to the computational cost of this algorithm is the explosion of the running time with the number of nodes. In the worst case the running time of Dijkstra's algorithm has complexity $O(|V|^2)$, where $|V|$ is the number of vertexes. However, assuming that every vertex is connected, the computational complexity can be reduced to $O(|E|\log|V|)$, where $|E|$ is the number of edges in the graph using binary heaps [29].

When scaling up the system, best path algorithms specially optimized for rapidly changing networks could be employed such as Bellman-Ford's algorithm [37] or the ones proposed by the MANET [38] group, used in the AODV [39] or OLSR [40] routing protocols for ad-hoc networks.

7. USER GUIDANCE

The vehicles subscribed to the service are fitted with an On-board Processing Unit (OPU) in order to provide position awareness and traffic guidance. A vehicle subscribed to the service needs to be aware of its position on the road. In the implemented demonstrator, this vehicle is fitted with a radio equipment similar to one used on the sensor nodes with which it interacts in order to provide position awareness. In an up-scaled version position awareness could be achieved via GPS or other positioning systems such as UTRAN positioning [41].

At start up, the OPU interacts with the user through a Graphical User Interface (GUI) shown in Figure 3 prompting for the destination point. The OPU queries the CMU as shown in Figure 8 for route information. The CMU-OPU communication depicted in Figure 8 is performed over aWiFi (IEEE 802.11b) wireless link and UDP/IP.

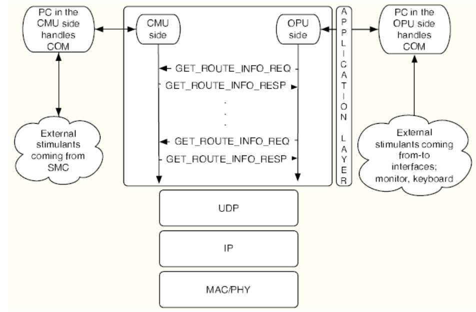

Figure 8. CMU-OPU communication.

The best path between the present position and the destination is calculated given the road situation at that time. The OPU asks the CMU to perform a best route recalculation after one of these events is triggered:

• A certain number of intersections have been crossed.

• A certain distance has been traveled.

• A certain amount of time has passed since the last update.

8. CONCLUSIONS

This paper presents an Advanced Traveler Information System that provides vehicles with user specific, on-demand route guidance based on real-time traffic information. The proposed ATIS takes into account the real-time average velocity of each road segment in the best path calculation algorithm that provides route guidance to the service subscribers. This service, provided over a wireless link, efficiently uses the available sensing infrastructures and radio communications resources in a cost effective and automated manner. Due to the modularity of the devised Advanced Traveler Information System, in an up-sized commercial version already deployed ATIS might be integrated in the system to provide some of the required services. A down-scaled demonstrator has been built and tested in order to provide proof-of-concept. This demonstrator implements an end-to-end solution (from data gathering to user guidance), where the real-time road segment average velocity has been included in the best path calculations in the form of weights.

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