The D-Systems Project - Wireless Sensor Networks for Car-Park Management

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***Abstract*—Wireless sensor networks are collections of autonomous devices with computational, sensing and wireless communication capabilities. Research in this area has been growing in the past few years given the wide range of applications that can benefit from such a technology. This paper reports on a joint project between The Tyndall National Institute and the Computer Science Department at University College Cork, Ireland in developing a novel miniaturised modular platform for wireless sensor networks. The system architecture, hardware and software will be discussed as well as details of the deployment scenario chosen for the project – a car park management system. Results and problems encountered during deployment will be presented**

Keywords-component Wireless Sensor Networks, deployment, car park monitoring

I. INTRODUCTION *(HEADING 1)*

This paper describes a highly modular, miniaturised wireless sensor platform that addresses the issues of flexibility, power-efficiency and size. The platform was developed as part of the D-Systems project [1] investigating the development of distributed intelligent systems. From a hardware perspective, the key objective of the project is to produce miniaturised autonomous sensing units that can be easily deployed and maintained in an everyday environment. The target sensing module being a 25mm cube incorporating commercial-off-the-shelf (COTS) microsensors, ICs for signal processing, computation, and wireless communications, as well as a power source, all combined together within a highly innovative packaging configuration. In regard to software and protocols the project had several specific research outcomes:

1. A model for maintenance in wireless sensor networks and a new technique for routing packets so as to minimise post-deployment maintenance costs.
2. 2. An algorithm for determining the best nodes in which to perform data aggregation, when operating with a limited data delivery time budget.
3. Two new energy-efficient medium access control protocols – one that is suitable for periodic scheduled data, the other for offering deterministic data delivery

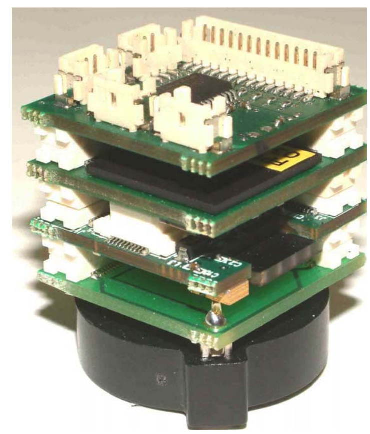

Figure 1. D-Systems wireless sensor Mote

II. CAR PARK IMPLEMENTATION

The target application demonstrator of the D-Systems project was a car park management system. Sensor networks are a natural candidate for car-park management systems, because they allow status to be monitored very accurately - for each parking space, if desired. Wireless sensor networks have the advantage that they can be deployed in existing car-parks without having to install new cabling for network and electricity to reach each sensing device. For this reason, wireless sensor networks also have use for road-side car-parking.

A. System Architecture

The overall architecture was guided by the principle of tiered functionality, with the lowest level comprising the sensing functionality, a middle tier dealing with data forwarding, and the upper tier handling data storage, processing and client interfaces. The architecture is depicted in Fig. 3 and mimics the actual physical topology used in our current deployment.

The DSYS25z [2] sensing nodes run Tiny OS Version 1.1.7, together with custom medium access control (MAC) and routing protocols, and a driver for the magnetic sensor. The application-layer software is responsible for reading from the sensor at a regular programmed period and forwarding the reading to a neighbour for multi-hop delivery to a base station (currently a PC). A Java-based server interacts with a serial-forwarder program to acquire and process the data. First, it determines the originating node, then it processes the new reading as follows: If the reading indicates a change in the current value for that node, then the server records the time at which the new packet was received and if it receives several successive updates indicating the same change in status then it accepts and records the change. The idea is to avoid reacting to transient changes, due, for example, to vehicles driving over a vacant parking space.

B. Server and Client Software

The server is a Fedora Core 3 Linux PC running Apache Tomcat 5 and MySQL. The main application updates the MySQL database as it receives fresh reports from the network. The user interface to the web application can be any Java enabled web browser. The web application shows a map of the car-park and which parking spaces are vacant or occupied. The interface allows different categories of users, including that of administrator.

It is possible to configure several aspects of the system, for example, new sensor nodes can be added, existing sensor nodes in parking spaces can be moved to a different parking space by dragging and dropping, and the reporting interval of the system can be changed. A user can also generate reports which can show the occupancy status of the car-park for a period of hours, days or months. The web application was implemented using Java Server Faces and HTML. The map which appears on the client browser is a Java applet. The Java build tool ant was used to manage the web application and to compile and install it as a web application in the Tomcat server.

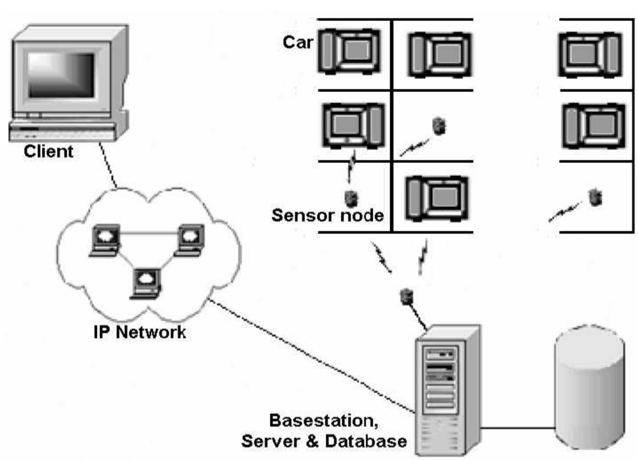

Figure 2. System Architecture

C. System Hardware

The 25mm WIMU has been designed based upon Tyndall's 25mm modular wireless sensor node [2,3] technology. The 25mm wireless node has been used to develop a platform for low volume prototyping and research in the wireless sensor network domain. It has been developed for use as a platform for sensing and actuating, for use in scalable, reconfigurable distributed autonomous sensing networks in a number of research projects currently underway at the institute.

The modular nature of the Tyndall hardware lends itself to the development of numerous layers for use in various application scenarios. Layers can be combined in an innovative plug and play fashion and include communication, processing, sensing and power supply layers.

For the car parking application, the DSYS25 hardware platform consists of a communications layer, a sensing layer and a power layer. The communication layer is comprised of an ATMega128L [4] micro-controller with a CC2420 Zigbee [5,6] compliant transceiver and a simple wire antenna [7].

For the detection of cars, a specific sensing layer including a magnetic field detector was developed. The magnetic field detector used for this application is the Speake FGM-3 [8] which uses 12mA of power and is operated at 3.3v. It outputs rectangular pulses with frequency inversely proportional to the magnetic field strength. The presence of metal changes the magnetic flux of the surrounding area and this change is shown by a change in the frequency of a quartz oscillator. Due to the high frequency of pulses generated (range 50-120kHz) it was decided to treat the sensor as an external clock whose frequency could be measured by counting how many pulses arrived during a fixed interval measured by the processors internal clock. The sensor output was connected to a 16-bit counter pin on the processor (TimerCounter3).

The power layer was replaced by a set of two AA batteries (or alternatively a 9v battery as shown in Fig 3) as sensor node lifetime is considered more important than node size. The resulting system is encased in a 15cm x 15cm plastic box that can be glued to the ground.

D. System Software

The platform runs a tailored version of TinyOS [9], an operating system designed at UC Berkeley and engineered to run in hardware platforms with severe resource constraints. The entire system can be described in terms of a graph of components and a scheduler. Components encapsulate functionality and state and provide well defined, bi-directional interfaces that can be "wired" to other components forming complex applications. The scheduler provides deferred execution of non-time critical and computationally intensive sequences of operations. Fig. 4 shows the component graph of the parking application implemented for the DSYS25 sensor nodes. The main part of the sensor application logic is implemented within the ParkLot component. The ParkLot component itself uses the magnetic sensor component Magn and the routing component DiffMultiHopRouter. The ParkLot

Figure 3. Car Parking Node in Enclosure

component sends and receives messages from the sink via the DiffMultiHopRouter component. The actual forwarding from node to node is handled by the CC2420_PEFRG_Radio component which handles the Zigbee transceiver specifics and implements the MAC protocol (Represented by the GenericCommPromiscuous component in Fig 4). Periodically, the sink broadcasts a message to the network which configures the behaviour of the ParkLot component and builds the routing topology. This broadcast message informs the sensor nodes of the sensing frequency f that has to be used. Thus, the ParkLot component is activated periodically as defined by f. When activated, the magnetic sensor is used via Magn to determine the presence of a car. The result of the sensing task is sent via the component DiffMultiHopRouter towards the sink. Faulty nodes can be detected by the sink if no sensor information is received from this particular node for a defined time period.

Since the deployed sensor nodes have to last for a significant amount of time, sophisticated power management of the nodes is necessary. The power management is implemented within several components used in the node. The ParkLot component is used to duty cycle the magnetic sensor. The CC2420_PEFRG_Radio component duty cycles the transceiver chip independently. The power management features of the TinyOS operating system are used to duty

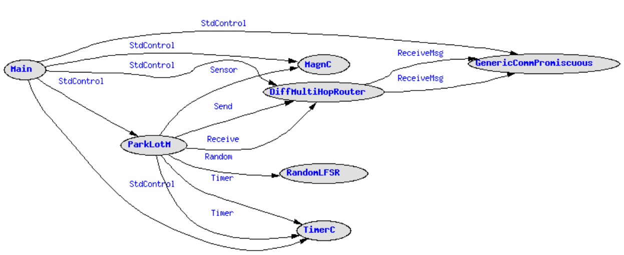

Figure 4. Component Graph of the parking Application

cycle the CPU. The simple design of the ParkLot application and the sensing and routing component chosen ensures that the resulting sensor system is easy to debug. Sensor readings are, for example, always sent to the sink, regardless of an actual status change. In-field processing is omitted to keep the sensors as simple as possible

III. EXPERIMENTAL EVALUATION

The system was extensively tested to evaluate the sensor, antenna, system connectivity and system routing. This section will summarise the results of each test. Further details are provided in [10].

Sensor Test: During tests it was found that the magnetic sensor was extremely sensitive to orientation and could produce vastly different results depending on its orientation. Essentially, the sensor detects the Earth's magnetic field and in some orientations the presence of a car above can produce erratic results. Therefore it was necessary to carefully deploy the nodes and calibrate in-situ. It was found that manual placement of the sensor along an East-West or West-East orientation produced the most stable results. In future deployments a more sophisticated sensor capable of self-calibration and correct operation regardless of orientation would be advantageous.

Antenna Test: A number of different antennas (planar, chip, flexible) were evaluated with the system to optimize the data transmission range and the simple wire antenna gave the best results [7]. However, the choice of antenna was not the only factor limiting connectivity.

Connectivity Tests: Extensive connectivity testing of the Zigbee radio was conducted in a number of different environments. The first test examined the characteristics of the transceiver in different situations. Basic communication range and the effect of deployment height above ground level was investigated. Furthermore, the effect of the uneven car-park surface was investigated. The second set of experiments examined the transceiver transmission characteristics in the target setting. Within the second set of experiments, different sender/receiver constellations in a car-park scenario are analysed. The different constellations are defined by the transmission direction and if sender and/or receiver are covered by parked cars. It can be concluded that:

- Communication reliability in the range of 0 to 5 meters is good.
- Communication reliability in the range of 5 to 10 meters is spatially and temporally unstable.
- Communication beyond 10 meters is nearly impossible.
- If sender and receiver are covered by a parked car, no communication is possible

Routing Test: A simple selective flooding routing scheme is used for the deployment. The protocol consists of two steps: topology discovery and data forwarding. For each step dedicated messages are used (called command and data messages) which are always sent as a broadcast. It can be seen from the data that the topology formation is flawed. In a great number of cases the perceived hop-count generated at each node using the broadcast message was not the same as the number of hops taken to reach the base station. This indicates that despite using static conditions it is extremely difficult to correctly build a routing topology.

Analysis of the data received reveals that the path taken by each message from a given node was not always constant. It could be seen that the routes taken by packets from node 5 often varies. This fact confirms that the network itself is unstable and therefore a flooded approach is the correct choice of routing protocol.

IV. CONCLUSION

The system was extensively tested to evaluate the sensor, antenna, system connectivity and system routing. The results of the connectivity tests & application tests can be summed up as follows:

- Connectivity in the test environment is not solely dependent on transceiver distance
- Uneven surfaces can be highly detrimental to connectivity. Connectivity is often asymmetrical to some degree
- The presence of a vehicle at the transceiver has significant effects on connectivity
- Transceivers are prone to bursty communication blackouts
- These communication blackouts are local and do not effect significant areas.

The presence of bursty patches of interference has implications

for the transport reliability of sensor data. Clearly when no communication can be successfully completed for a significant period of time, often in the order of seconds, it is unwise to attempt to improve data transport reliability by the use of acknowledgements or retransmissions unless such systems include sufficient temporal displacement to avoid communication blackouts. In other words one should not try to retransmit before waiting for a reasonably long period of time. Naturally, the employment of such a reliability enhancing system would increase the perceived latency at the application leading to decreased responsiveness and performance from a user perspective and is therefore not desirable. A more reliable system can be envisaged by making use of the fact that the communication blackouts experienced seem to cover a very small area. Thus any system that increases redundancy using a spatial dispersement strategy should be more successful with minimum cost in terms of delay. In effect this amounts to limited flooding and diffusion approaches.

ACKNOWLEDGMENT

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