NON-RESTRICTIVE LINKING IN WIRELESS SENSOR NETWORKS FOR INDUSTRIAL RISK MANAGEMENT

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ABSTRACT

The OSIRIS project addresses the disaster management workflow in the phases of risk monitoring and crisis management. Risk monitoring allows the continuous observation of endangered areas combined with sensor deployment strategies. The crisis management focuses on particular events and the support by sensor networks. Four complementary live demonstrations will validate the OSIRIS approach. These demonstrations include water contamination, air pollution, south European forest fire, and industrial risk monitoring. This paper focuses on the latter scenario: the industrial risk monitoring. This scenario offers the special opportunity to demonstrate the relevance of OSIRIS by covering all the aspects of monitoring, preparation and response phases of both environmental risk and crisis management.

The approach focuses on non-restrictive linking in a wireless sensor network in order to facilitate the addition and removal of nodes providing open interaction primitives allowing the comfortable integration, exclusion, and modification. A management layer with an event-triggered and service-based middleware is proposed. A live lab with real fire is illustrated.

Keywords

In-situ sensor network, industrial risk monitoring, crisis management, live demonstration, OSIRIS.

INTRODUCTION

OSIRIS stands for <u>O</u>pen architecture for <u>S</u>mart and <u>I</u>nteroperable networks in <u>R</u>isk management based on <u>I</u>n-Situ <u>S</u>ensors, funded by the European Commission in the GMES environment.

One major aspect of wireless sensor networks is the network management, where abilities of self-healing and self-organisation are significantly relevant during crisis management as well as in the monitoring phases. Existing strategies must be analysed with focus on the following research topics:

<u>Sensor coverage</u>

The required coverage might not be obtained due to changes in the environment or failures of sensors. Hence, the sensor network has to reconfigure itself to re-establish the intended coverage.

<u>Network connectivity</u>

A sensor network has to report the events to the data processor. In case of node failures or obstacles inhibiting the communication, the network communication must be flexible. The best way of network organisation has to be elicited.

Network Coordination By Localized Algorithms

The coordination of a sensor network can be improved by using localized algorithms (Estrin et al, 1999), in which simple local node behaviour achieves a desired global objective. Clustering is one global objective, which allows the efficient coordination of local interactions. An advanced scalable behaviour can be achieved by localised clustering with an increased number of nodes.

Cluster-head sensors are elected by a localized cluster algorithm first, because every sensor is associated with a cluster-head sensor as its parent. This process is recursively used to build a cluster hierarchy. All sensors start off with the lowest level of 0, they wait for a certain wait time proportional to their radius, and then they start a timer if they do not have a parent. If the promotion time expires, these sensors promote themselves as level 1.

A cluster-head sensor can locally determine whether it should participate for example in an object triangulation. The energy consumption is low, because these sensor algorithms use only local information. The so-called adaptive fidelity algorithms conserve energy as well, but it reduces the sensor fidelity.

Energy Efficiency

Communication latency and capacity in ad hoc wireless networks can be improved by a distributed coordination technique (Chen et al, 2001). The algorithm is called “Span”, which adaptively elects coordinators from all nodes and rotates them. Span coordinators stay awake and perform multi-hopping packet routing, while others remain in power-saving and check periodically whether they should become a coordinator or go to sleep. Only local information is required for these decisions.

A node takes the role of a coordinator if it discovers that it can not reach each other either directly or by means a coordinator. The amount of energy savings does not increase significantly as node density increases.

Formal Communication Models

Formal communication models (Yu et al, 2005) are required for wireless sensor networks due to continuing advancements in sensor node design and increasingly complex applications. Two models are defined: the Collision Free Model and the Collision Aware Model. The Collision Free Model (CFM) is very powerful in programming due to its abstraction in all details of low level channel contention and packet collision away from the algorithm designers, but it does not really capture the issue of packet collision. The Collision Aware Model (CAM) defines that packet collisions occur when several nodes try instantly to communicate with their neighbours.

Decentralised Approaches

A decentralized approach to the solution of the distributed information gathering problem is presented in (Makarenko et al, 2004). The decentralized principle is characterized by the following constrains: lack of central services and facilities, so that messages and communication must be maintained on a strictly peer-to-peer basis. Another characteristic is that network components do not have any global knowledge of the network topology; components can only know about connections in their own neighbourhood. Thus, this approach claims to have advantages in scalability, robustness, and modularity.

The Active Sensor Network architecture is formed by Information Fusion, Decision Making, and System (Re-)configuration. The structure of the solution can be categorized in four areas: Network algorithms, Information fusion algorithm, Utility function and Control solution algorithm.

The Information Fusion decentralized algorithm states that the incoming data from remote sensor nodes is assimilated by the local sensor node before being communicated to the next nodes. So, in spite of the number of incoming messages, there is only a single outgoing message to each linked node. Hence, the sensor network can be scaled indefinitely.

The Decision Making decentralized algorithm can be implemented by two different algorithms. The first one, coordinated control algorithm (Grocholsky et al, 2003), predicts and maximizes the expected information obtained from local sensors. The second one, cooperative control algorithm (Grocholsky, 2002), involves each decision maker in anonymous negotiation based on propagation of expected observation information.

Another decentralized approach is presented in (Nittel et al, 2004), concentrating on how to disseminate relevant information to mobile agents within a geosensor network. Three different strategies for efficient information dissemination were presented. The first one, Flooding, states that if a node encounters an event or receives a message, it must send the information to every single node within its communication range. The second one, Epidemic, each node only informs to n other agents about an event. The third approach is location-constrained, in which information is only forward in proximity to the event and then discarded.

The advantages include robustness, performance and scalability. The results were only simulated and the three strategies stated before were proposed for scalable, peer-to-peer information exchange. These strategies were tested based on the level of ignorance, redundancy, and degree of redundancy. The simulations showed that the proximity communication strategy provides an efficient compromise in terms of information dissemination in MAGNET (geosensor mobile ad hoc network) efficiency. The levels of ignorance achieved using the proximity strategy are comparable to those of the flooding strategy. At the same time, the proximity strategy does not lead to as high levels of information redundancy as the flooding strategy.

Multi-Channel Support For Dense Wireless Sensor Network

Currently, most wireless sensor networks (WSN) applications assume the presence of single-channel Medium Access Control (MAC) protocols, but a dense wireless sensor network requires a multiple channel support (Durmaz et al, 2006).

The LMAC (light-weight and energy efficient MAC protocol proposed for WSN) is an energy-efficient medium access protocol designed for WSN. This protocol allows nodes to access the wireless medium on a time-scheduled basis over a single frequency channel. LMAC also takes into account the division of time into slots which are later organized into periodic frames. If a node sends information, it takes the control of a timeslot. Timeslot selection mechanism in LMAC is fully distributed, thus needs no base-stations or central authorities to decide and allocate the timeslot to the nodes. For this selection only local information is used.

Scientific and technological objectives

The sensor network requires a dynamic management, capable of integrating or excluding sensors easily. New integrated sensors may broaden the coverage or focus at a special area of interest and excluded sensors might provide nuisance information. Strategies for the deployment of sensors are elaborated depending on different risk criteria. A sensor web enablement architecture ensures an easy linkage of highly dynamic services with spatio-temporal information. A network adaptation layer defines a middleware layer with simplified communication access for applications and services. The heterogeneous information of sensors is harmonized for the data processing in order to obtain standardized information services. An important aspect is the data transmission from the event generating sensor node to the appropriate application, which generates the dedicated service.

NON-RESTRICTIVE LINKING IN WIRELESS SENSOR NETWORK

Sensor networks mostly refer to pre-build modules like device interfaces or sensing algorithms. Application-specific software modules have to be developed and existing elements have to be integrated. But the resulting control application is difficult to maintain. Changes like adjoining or withdrawing sensors and their associated code often require extensive adaptations.

Non-restrictive linked wireless sensor networks overcome the requirement of intense modifications by integrating a management layer. This layer provides open interaction primitives allowing comfortable integration, exclusion, and modification.

A further characteristic of the non-restrictive linking is that changes in one part of the system do not affect other parts of the system. The abstraction layer facilitates the design of the architecture elements by reducing the design process to the basic functionalities.

Event-Triggered And Service-Based Middleware

The event-triggered messages provide an abstract aggregation of publish/subscribe and message queues, enabling sensor nodes to send and receive messages as well as dynamically requesting interest in receiving specific messages. The service-based distribution uses a service as an abstraction to encapsulate functionalities. Application requirements can be satisfied by dynamic selection and invocation of services. Though it should be noted that the dynamic selection of any required service demands common descriptions of services and requirements.

Multifunctional Sensor Nodes

Sensor nodes with multifunctional capabilities are developed which match the needs for flexibility, self-managing and resilience to most of environmental interference. The thresholds of the measured sensor data are remote adjustable therefore allowing to be adapted to specific environmental conditions. Further, methodologies are elaborated to incorporate sensor knowledge about itself:

- Abilities
- Location
- Data type
- Group & relation
- Network awareness

The nodes are augmented with intelligent and flexible adaptiveness to available network resources

- Adjust sensor refresh rate to network latency
- Enabling the buffering of sensor data in data sinks
- Adjust sensor data amount to network transfer rate
- Synchronous or asynchronous mode

Information display

Information sharing methods are created for a seamless access to distributed information services. This includes a focused view on temporal clusters of sensors into virtual groups with specific capabilities at specific locations. Web mapping solutions are achieved, enabling the fire suppression forces to:

- Indicate the sensors with localized information
- Subscribe to events on sensors
- Design the needed workflow

This allows the integration of both human and technical resources in order to enhance the task force performance by providing tailor-made information according to the user tasks. They are supported to interpret information from a vast array of diverse sources delivered by data mining routines.

INDUSTRIAL RISK MONITORING

Main focus for this demonstration is the support of task forces with regard to disaster prevention, the preparedness and the intervention in case of disaster. It will concentrate on the detection of fires within industrial-like buildings (see figure 1). Beside the detection of fires there exist the problems of false alarms. Most automatic fire alarm systems are a legal requirement or have been installed to provide fire safety, and it is essential that they operate efficiently at all times. Obviously, false alarms reduce the effectiveness of any early warning system.

Figure 1. Applied fire fighting in the live training lab in Aachen/Germany

The premises offer an optimal environment for controlled, reproducible, and variable conditions with different fire places and several access points to the building. The fires are propane driven and can vary in their size. Flash-over can be induced, too. Gas sniffers automatically prevent a propane overload. Three different rooms are included, all equipped with sensors. An exhaust system with induced draught fan extracts heat and smoke at 10.000 m^3/h.

A sensor chain consisting of Infrared and thermal sensors, smoke detectors and webcam are deployed to monitor the premises. Areas of special interest which may contain especially dangerous goods like inflammable liquids can be monitored by a special set of sensors. The combination of the different sensors shall facilitate the detection of false alarms and precise localization of fire or danger areas within buildings.

The chosen test case detects false alarms as well as a fire which will be verified by networked in-situ sensors. If a sensor detects a fire, other sensors will verify the incident. This verified incident will set off an alarm. Information services will assist the task forces to assess the impact of the risk and to elaborate a corresponding fire fighting strategy. The services include a mapping service which specifies fire starting point, fire expansion, and building access.

CONCLUSION

This papers proposes the integration of non-restrictive linking of sensor nodes in a wireless network in order to facilitate changes in the configuration. This strategy is enclosed in the European project OSIRIS, which develops an open architecture for smart and interoperable networks in risk management based on in-situ sensors. Although the proposed approach demands additional effort for developing strategies, it is expected to prove that the OSIRIS approach is a valid strategy.

ACKNOWLEDGEMENT

OSIRIS is an Integrated Project co-funded by the INFSO DG of the European Commission within the RTD activities of the Thematic Priority Information Society Technologies.

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