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A methodology for designing robust and efficient hybrid monitoring systems ☆

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ABSTRACT

A modern distributed monitoring system is a network of sensing units that acquire and transmit data towards a base station. These systems can be used to monitor infrastructures such as tunnels, pipelines and mines, supporting the detection of abnormalities such as faults and incidents. Wired and wireless solutions can be used to address inter-unit and remote communications, with the ultimate choice of technology determined by the monitoring application and its constraints. When an accident affects the monitored area (e.g., fire or explosion), the collapse of part of the structure on which the system is deployed may result in a partial or total impairment of system performance. In such circumstances, the system is unable to provide monitoring data that is required to assess the residual risk and to evaluate the accident dynamics.

This paper presents a methodology for designing robust wired monitoring systems that can recover from faults, failures or accidents by relying on hybrid wired–wireless technology and a self-configuration mechanism. The default wired communications is based on a fieldbus and changes to hybrid wired–wireless communications when the network or portions of it are down. The identification of the system segments on which unit data has to be routed for delivery is performed by an energy-aware algorithm and mechanisms that endow a certain amount of intelligence to the units.

The proposed solution does not introduce restrictions on the number of data collection base stations or on the network topology. Experimental results show that the solution is effective and provides robust mechanisms for dealing with topological changes while conserving energy.

1. Introduction

Monitoring solutions relying on wired communications (Fig. 1 (a)) are the traditional and often preferred choice for infrastructures such as tunnels, pipelines and mines. Such a monitoring system can be used to detect abnormalities such as faults and incidents, as well as support continuity of service and emergency management efforts. In these environments, the presence of other facilities such as power supply and aeration systems makes the deployment of monitoring systems relying on cables for data transmission natural, straightforward and cost effective. Some technologies such as powerline communications [13] permit power supply and data communications to share the same physical medium. The main drawback of a wired system is the need to deploy cables that, in addition to their cost, could be damaged during an accident in the monitored area, partially or totally impairing data transmission during the emergency situation.

To provide robust monitoring systems, in terms of the ability to reconfigure the units following an accident so that adequate data conveyance and quality of service are provided, pure wired communications must be augmented with

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wireless technology. The resulting hybrid wired–wireless system is shown in Fig. 1(b), where the sensing units are equipped with wired and wireless communications interfaces. Default communications use a fieldbus, while wireless communications is used in the event of faults, accidents and attacks to connect physically disconnected segments of the network. When no connections are provided to some units, they can simply serve as data loggers.

Many monitored environments have heterogeneous topologies. For example, in the case of a mine, there could be several accesses, loops in galleries and tunnels with tree-like branches. In such a scenario, a routing policy must be adopted, because multiple paths may be available for data delivery and more than one base station may be used for data collection (e.g., near each entrance of the monitored environment). Furthermore, as a consequence of an accident (e.g., structural collapse), portions of the monitoring system may be out of order, breaking previous-established communication paths. This problem can be addressed only by reorganizing, in real time, the functionality of the units and the routing paths to use the remaining working portions of the system (Fig. 1(b)).

Faults can also affect power supply to the system. To address this problem, backup energy mechanisms must be provided at the unit level or cluster of units level (e.g., using batteries and supercapacitors). Energy harvesting solutions should be considered where feasible, and local intelligence could be implemented to manage the residual energy.

This paper presents a methodology for designing robust and efficient monitoring systems based on hybrid wired–wireless communications. The main contributions are:

- Design of a hybrid wired–wireless system architecture for isolating wire faults and replacing compromised sections with wireless links, while preserving as much of the wired communications as possible. No restrictions are made about the system topology and the number of base stations used for data collection.
- Development of a routing solution for managing data delivery in a dynamic and distributed manner in a hybrid framework. Data is always delivered in a manner that favors paths that minimize energy consumption.
- Specification of mechanisms that dynamically organize hybrid communications between units and manage the tasks to be accomplished, including power saving policies.

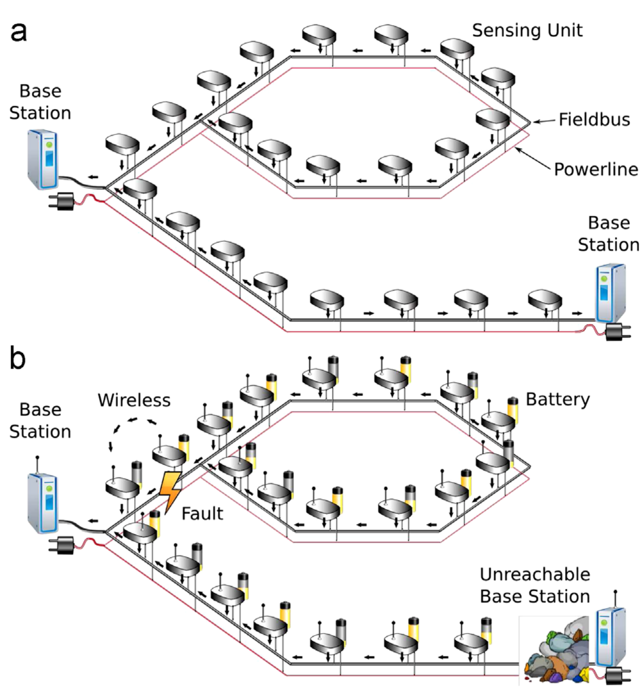

Fig. 1 – (a) Typical wired monitoring system. (b) Hybrid monitoring system.

Some research has been conducted in the area of hybrid monitoring systems. Ding et al. [3] have proposed a wireless-based sensor network for mine monitoring, but point out that a hybrid wired–wireless monitoring system would be a preferred solution in such environments. Their idea has been advanced in [6,9], where the authors present infrastructures that incorporate some wireless units that transmit data to specific aggregating units, which are connected to a fieldbus that serves as a backbone to a base station. Jaman and Hussain [7] employ a similar architecture for structural monitoring.

The approaches discussed above do not deal with the management of faults that can affect a system. Mohamed and Jawhar [10] present a hybrid system for pipeline monitoring, with sensing units deployed along the pipeline and connected using a single unit-to-unit wired link. When a failure occurs to a unit or wired link, the system is locally switched to the wireless mode. This architecture involves significant overhead and energy consumption, primarily because each unit has to receive and forward the data stream to the base station. Moreover, only a linear topology is considered (due to the nature of the application) without providing a routing policy.

This paper is organized as follows. The next section describes the hybrid wired–wireless system architecture, along with the relative routing solution for managing data delivery. Section 3 discusses the protocols used for unit management in the hybrid communications mode. Section 4 describes the experimental results and Section 5 presents the conclusions.

2. Hybrid wired–wireless architecture

The proposed monitoring system architecture employs sensing units that are connected via a transceiver interface to a fieldbus and are organized in clusters. In the case of system faults, backup wireless communications and dynamic reorganization mechanisms are adopted in the affected sections to ensure that monitoring activities can continue.

2.1. *Cluster organization*

Accidents such as fires and explosions generally introduce faults that compromise the quality of service of communications along a bus. Typically, two termination resistors are needed at both ends of a twisted-pair-based bus to ensure