Managing Enterprise Resource and Environment through Real-Time Tracking, Monitoring and Actuation of Enterprise Objects using Internet: a Conceptual Framework and Test-Bed Implementation

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Abstract. In this paper, we present a unified framework for both asset and environment visibility of an enterprise through real-time tracking and monitoring of enterprise objects using the Internet. The objects that are monitored can be personnel, equipment or an environmental condition. The architecture also enables the control of asset utilization by triggering actuators. Active RFID tags, combined with sensors and actuators, form a wireless mesh network based on IEEE 802.15.4. We develop a new routing algorithm oriented for these tracking applications where the network is sparse but comprises of extended legs. We elaborate a test-bed implementation for tracking underground miners and equipment along with monitoring the underground environment for possible emission of toxic gases.

Keywords: Internet of Things, 802.15.4, Remote Tracking, Static Routing.

1. Introduction

The availability of consistent, accurate and timely information greatly improves the quality and speed of planning and decision making in any organization. Total Asset Visibility (TAV) [10] is a term, used in US Department of Defense's logistic practices, that implies knowing where assets are at all times. It also implies having a unique identity for each item and knowing what is happening to it, as it happens. TAV can usefully be applied to any organization for improving enterprise visibility. Timely and accurate information on the location, movement, status, and identity of units, personnel, equipment, material and supplies can improve the resource utilization by a great extent.

An Enterprise visibility system is not confined to asset visibility only. The same framework can be used to monitor the enterprise environment, to protect it against possible damage by terrorist attacks, fire or emission of toxic gases (in case of chemical industries). Wide variety of sensors connected together using wireless sensor networks forms the core of this **Environment Visibility** System.

Moving a step further towards a "better" visibility, all this information should be available in real-time from anywhere. This "anywhere" accessibility of information through the Internet, which in turn is linked with the core visibility system in an organization, enables a corporate manager to access relevant enterprise information in real time, as and when needed.

This paper presents a unified framework for both asset visibility and environment visibility of an enterprise through real-time tracking and monitoring of enterprise objects using the Internet. It also allows controlling the asset utilization and the environment by triggering actuators, which are also part of the enterprise objects. The core objective is to develop a system that helps not only to view but also to control enterprise objects through the Internet.

The paper is structured as follows. Section 2 develops a conceptual framework and section 3 explains the detailed system architecture and its three components: the wireless mesh network, central server and the Internet connectivity with the web end point. The practical implementation of the system for tracking underground miners and mine equipments with real-time environment sensing to warn against emission of toxic gases is presented in Section 4. The related work, in the area of the “Internet of Things”, is discussed in section 5. We provide the scope for further work and conclude in Section 6.

2. Conceptual Framework

Small, autonomic wireless devices, cheaply priced and capable of forming communications networks are expected to be the next technological innovation to bring about a mass cultural change. This new concept is due to the emergence of Personal Area Networks (PAN) where billions of devices are inter spread in the everyday activities of humans. The devices help organize, manage and control a host of equipment and services. The impact of this new paradigm is often compared to the digital revolution brought about by the Internet in the late nineties.

The Personal Area Networks comprise of, typically, sensors and actuators which are capable of forming wireless networks among them and are designed to run on batteries for prolonged periods of time. These devices and such networks need to support a low data rate and the computational capability is restricted. Low data rate protocols have been designed specifically for these needs lately, a significant deviation from the trends of building high-bandwidth networks. The protocol ratified by IEEE is 804.15.4 in 2003 and updated in 2006 [6].

The “Internet of Things” paradigm is proposed to control such devices from a remote location through the Internet. For example, you could turn on your oven, or check the quantity of food in the refrigerator from your office, located miles away. Further, the devices could be automated to talk to each other over the Internet. The ITU, in its report on the Internet of Things [7], has foreseen the emergence of a new ecosystem due to the Internet of Things. The key players of this ecosystem would be: the Government (and its regulations), the Social System (and the acceptance of ubiquitous technology by the users), the commercial players (the economic viability of the technology) and the R&D Organisations (the usability of the technology).

In this paper, we have developed an end to end architecture for such remote visibility of enterprise "objects" and remote actuation necessary for controlling these "objects". The architecture comprises of three basic components: (a) the wireless mesh network, consisting of RFID tags, sensors and/or actuators, (b) the gateway and the central server and (c) the Internet.

3. Detailed System Architecture

As depicted in figure 1, the proposed architecture has three components: Wireless Mesh Network, Central Server or Control Station, any web-enabled device accessing the central server through the Internet.

3.1 Wireless Mesh Network

Wireless Mesh Network, as its name implies, is a type of network where each node in the network can communicate with multiple wireless nodes, thus enabling better overall connectivity. A wireless mesh network has two kinds of nodes: the mesh routers and the mesh clients [1]. The mesh clients can be made to communicate with multiple routers/other clients, or arranged in a hierarchical fashion where every client has a single router as its parent. A major advantage of this kind of networks, other than self-forming and self-healing capability, is multi-hop routing. This means that data from a wireless node can jump through multiple nodes before delivering its information to a remote host gateway or controller that collects the data from tags for further processing. Low power mesh networking, sensing and active RFID-based real-time location tracking is a combination that has enabled us to design systems for tracking, locating and monitoring people and things and environmental conditions.

Passive RFID tags (RFID without a battery) [13] is already driving shifts in supply chain and retail capabilities for automatic identification of objects. However, Active RFID has much broader potential in the enterprise. Firstly, active RFID can form a wireless mesh network, providing automatic, dynamic visibility into what is going on in and around the enterprise. Secondly, active RFID technology, if combined with sensors and actuators in a networked environment, enables a spectrum of applications that can exponentially increase visibility and monitoring. Offering much more information than passive RFID, sensors can monitor and record conditions like temperature, humidity, pressure, chemical concentrations, pollutant levels and so on. The mesh network proposed here has three components which are elaborated below.

3.1.1 Active RFID Tags with Sensor /Actuators

Designed for fixing on different types of objects/assets (wearable tags for humans), active RFID tag is versatile in its usage. It is possible to attach analog sensors, digital sensors and actuators using its ADC and digital Input/Output ports. So, the same device can be used as RFID tag for tracking objects, as a sensing device to read the environmental condition, as a messaging device to send pre-coded emergency messages to remote control stations or as an alarm device to receive the alert message sent from the remote station. These active RFID tags are battery-operated devices that are designed to communicate with a Gateway in its vicinity. In order to communicate with the gateway that is out of the communication range of a tag, sufficient number of routers may be introduced in between the tag and the gateway so that data can be propagated in multi-hops.

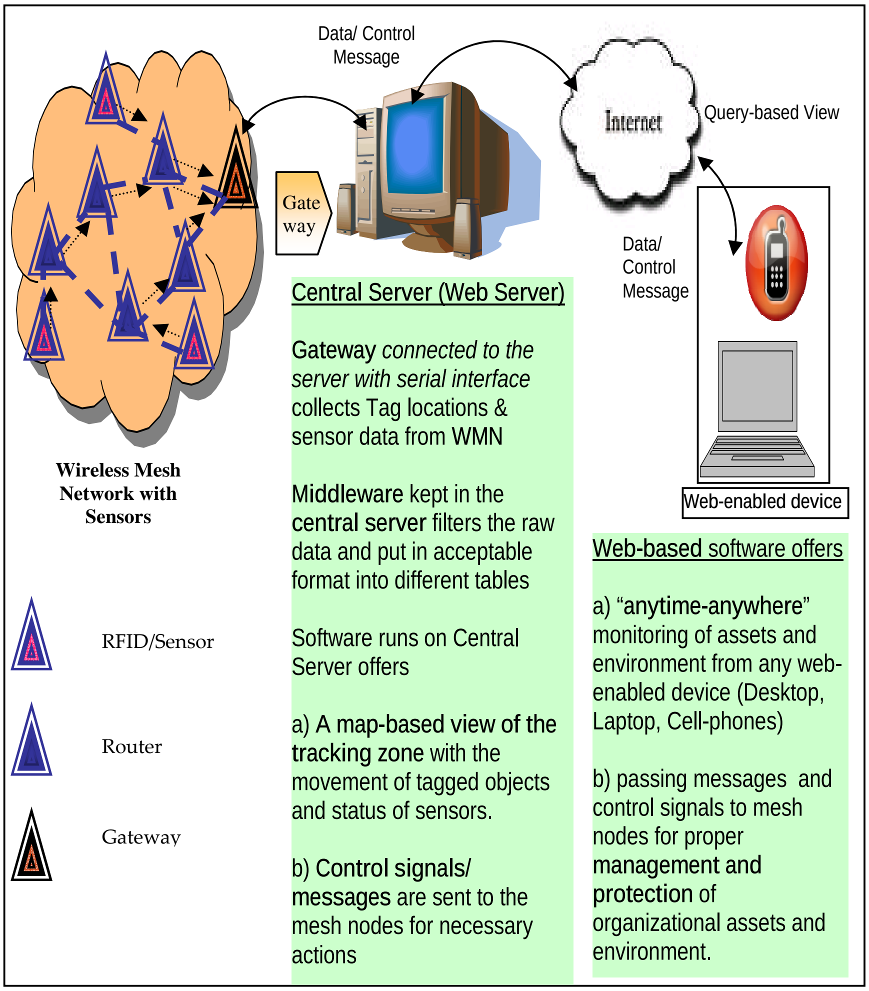

Fig. 1. A conceptual Framework for Tracking, Monitoring and Actuation of Enterprise "objects" through the Internet

3.1.2 The Gateway

The Gateway is essentially the master controller that coordinates the formation of mesh network, collects the tag data and transfers it to the host computer. On one hand, it supports bi-directional communication with active RFID tags either directly or via intermediate routers. On the other hand, it has wired / wireless interfaces to the host computer so that the tag data received by the gateway can be sent to a host computer (Laptop, PDA, PC) for further processing.

3.1.3 The Routers

Routers can be used for range extension of the active RFID devices. In real-time location system (RTLS), routers are fixed at strategic locations within the tracking zones forming wireless mesh network with other routers, gateway and active tags in its vicinity. Location of a tag is determined in terms of the locations of these fixed routers.

3.2 The Central Server

The data obtained from the wireless mesh network is primarily stored in different staging tables in a server database and subsequently processed and analyzed by the software to get a real-time view and status of the tracking and monitoring zone.

3.3 Accessing the Central Server through Web-Enabled Devices

Web-based Tracking and Monitoring system offers the flexibility to track and monitor the organizational resources and environment through internet providing *"anytime anywhere"* visibility of the enterprise. Remote users can track the organizational resources and monitor the environment based on the data accumulated in the server at the control station and based on that user may take some control decisions. Other features like, *Tracker, finder, Sensor monitor, Response handler, Report generator, Query Manager and Message viewer* are also available in the web-based version of the software.

4. A Test-bed Implementation for Underground Mines

Underground mines are disaster-prone where disasters occur due to inundation of mines with underground water, or, explosion due to excessive emission of poisonous gases, or, lack of adequate roof support. During disaster, the main problem is to identify the pits or tunnels where exactly the workers are trapped. The mine authorities can only count the cap lamps to conclude the total number of miners trapped inside but have no clue about there locations. Therefore, tracking and monitoring of miners is a basic need in hazardous environment of mines. Apart from miners, continuous tracking and monitoring of mining equipments is also necessary for better resource utilization and improve productivity. Moreover, an early warning system to detect the excessive emission of poisonous gas or a system to prevent the entry of miners in an unsafe zone inside mine is also necessary to ensure mine safety.

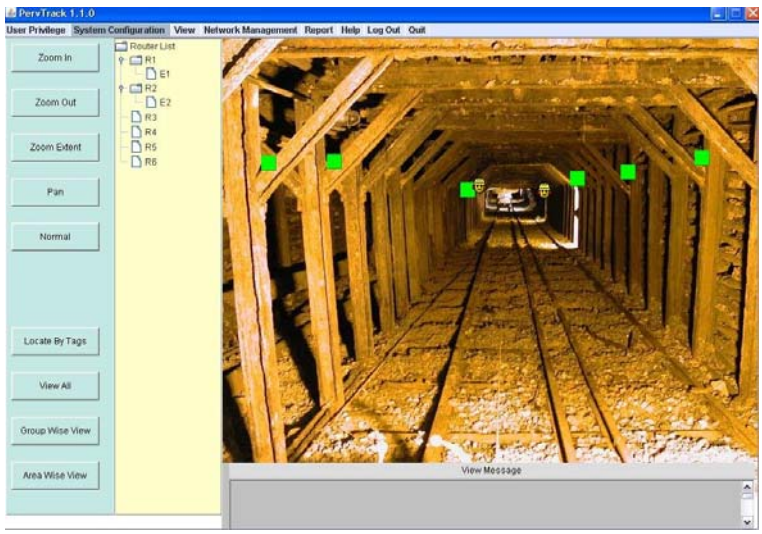

Fig. 2. Locating workers in a Mine Shaft

In our proposed system, cap lamp allotted to a miner has an additional attachment that is essentially an IEEE 802.15.4-enabled RF Active Tag. Each tag carries a unique identification number and it sends beacon periodically to inform its presence. Similar devices are statically placed as routers at different strategic locations covering the entire underground mine to uniquely identify each area within the mine. During a shift, tagged miners work at different areas inside mine and a router in an area captures unique identification numbers periodically emitted by all the tags present in that area. So, the location of a tagged miner or equipment can be determined in terms of the location of its nearest router. These active tags and routers form a rapidly deployable wireless network on ad hoc basis inside the mine which serves as a network backbone to carry the tag ids and their location information in multi-hop from underground to the control station on the surface that in turn is connected to Internet. The miners could be now tracked from a central or sub-central control points as well as through Internet.

Tracking performance is evaluated in a real-life scenario where a network is configured replicating the floor plan of a mine. We have used 8 Routers 1 Coordinator and 10 tags to evaluate the system as per the configuration shown in fig 2. We have also configured the software system accordingly by loading the map of the site and placing the routers on the map as per their placement in the actual site so that the map with routers placed on it maps the actual tracking zone.

5. Related Work

The International Telecommunications Union (ITU), in its report on the future of the Internet, coined the term “Internet of Things” in November 2005. The report envisioned a case where we could see “remote controlled clothing, cars that alert their driver when they have developed a fault, managers who check on workers through the RFID devices embedded in their phones, and bags that remind their owners that they have forgotten something” [2]. It highlighted the situation where humans would be the minority in generating and using information over the internet. Devices and “things” would be smart enough to communicate with each other and establish a “thing to thing” network.

Research on establishing a practical “Internet of Things” has been sedate with little articulated work. [4] develops an architecture for a uniform protocol architecture between different things with the Internet forming a major chunk of the communication network. RFID tags are considered for the wireless mesh network. The architecture proposes adapting the TCP/IP protocol structure for wireless needs termed STP/SP (Smart Transport Protocol/ Smart Protocol). Similar work has been done in [11] where the active RFID tags are built to run on the Host Identification Protocol (HIP). This makes it possible for the tags to talk to IP endpoints on the Internet.

The Internet of Things has also spawned interest in the middleware architecture which acts as the gateway between the sensor networks and the Internet. [8] looks to develop abstractions for the sensors in a network and thus support a flexible architecture and zero programming of the sensor devices.

The architectures developed so far explore a homogeneous protocol structure from an end to end perspective. However, the devices and the networks are diverse enough to predict the formation of a single standard that fits best in every circumstance. The research in each aspect of the “Internet of things” has been significant with the development of structures efficient for their respective needs. Our architecture thus uses the already well defined protocol structures in each domain and develops an abstraction to the underlying structure.

6. Conclusion

In this paper, we have developed a unified framework for asset visibility environment tacking through the Internet. The architecture comprises of the sensor network with active RFID devices on one end and the web enabled asset management interface on the other. The protocol conversion is made at the gateway which links the mesh network to the Internet.

There are a few aspects we would like to address in the future. The unified framework developed in this paper, gives the power of abstracting the underlying architecture at the gateway. The underlying structure and nature of the network does not affect the architecture of the "Internet of Things". However, this abstraction requires a formalization of the services that must be offered at the mesh network and gateway interface. This set of services can only be determined when the entire end to end service requirements are ascertained. We, thus, would like to develop a structured approach and framework for identifying and designing the services at the interfaces.

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