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Mobile Asset Utilization Improvement using Wireless Mesh Network based Real Time Locating System in Manufacturing Industries

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Abstract

The utilization of assets, measured as the ratio of the current output versus that achievable maximally, forms the basis for the profitability of a firm. Measuring the utilization of assets such as a production tool is simple as the output is amenable to measurement. However, how do we measure the utilization of assets that are mobile (Fork-Lift-Trucks, Dozers, Loaders, etc.)? On most occasions, the number of mobile assets needed is estimated on a conservative back of the envelope calculation that directly results in overbuying the assets and consequently, a lower utilization rate. In this paper, we have developed an IEEE 802.15.4 based Real Time Location System (RTLS) incorporating a closed loop control to capture the mobility and utilization patterns of mobile assets. We report our experiences and results from the deployment of such a system to track the movement of Fork-Lift-Trucks in the factory premises of a manufacturing plant in India. We show the insights generated from the utilization patterns, the bottlenecks and formulate an optimization problem that gives the best possible utilization rate and the number of assets needed for the actual demand. Our results not only show the technical feasibility of the system in a real-life scenario but more importantly, depict the value created by a real-time tracking system.

Keywords - RTLS Deployment; IEEE 802.15.4; Asset Utilization Optimization.

1. Introduction

Wireless mesh network is a new and upcoming technology that has grabbed the attention of the technical community over the last decade. It opens the possibility of numerous applications ranging from industrial to consumer use. The wide interest from the technical community is largely due to the immense number of application areas enabled by this technology and the unique technical constraints that give scope for innovation.

In this paper we implement and deploy an active RFID and wireless mesh network based real-time locating system (RTLS) to track the mobility of the Fork Lift Trucks (FLTs) at the production facility of a leading aluminum manufacturing company in India. A closed loop control system was also implemented to improve the utilization rate

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by identifying an asset that is idle and commissioning it to meet the demand. We track the movement of FLTs in the factory premises through an IEEE 802.15.4 based wireless mesh network [4] for a period of 100 hours. With the gathered data we present an accurate account of the asset utilization and pinpoint areas of bottleneck. The true mobility pattern enabled us to devise an optimization model that gives the ideal number of assets needed and helps to realize a closed loop control system to dynamically allocate assets at different point-of-requests, providing a precise reading on the cost savings and the return on investment (RoI). Our results and analysis shows the value in the tracking of mobile assets and the technical feasibility of the IEEE 802.15.4 standard for such needs.

Our paper is structured as follows. In the following section we discuss similar attempts made elsewhere to improve the asset utilization using RFID technology. Section 3 explains the detailed technology implementation and section 4 describes the deployment details for real time location monitoring. Elaborate analysis of the aggregated tracking data is presented in section 5, clearly identifying the performance bottleneck with FLT utilization ratios and introduces the closed-loop control mechanism to improve on the utilization of FLTs. Section 6 summarizes and concludes our work.

2. Related Work

Increasing popularity of RFID based asset tracking mechanism has drawn attention of the researchers to come up with effective deployable solutions to handle asset under-utilization. However, most of the work has been concentrated on the hospital industry to improve their operational efficiency [5, 6, 10, 11]. ZigBee based asset tracking system was used in [10] to track critical equipment in the hospital emergency rooms, wheelchairs, and other medical apparatus on a real time basis. The study showed the asset utilization ratio at the hospital to be 60%. The integrated centralized visualization software was able to provide the management with a daily analysis of the utilization pattern which in turn enabled proper asset usage and better patient care.

Monitoring the mobile patient course and work flow [7] is another critical aspect in the healthcare industry. In [11] the raw data generated from the RFID based tracking system was processed through a simulation model and used for inferring general statistical distributions of assets utilization time and rules characterizing the operations of a hospital; although there had been no closed loop control mechanism in place to increase the asset utilization.

Timely and relevant information on the location, status and condition of mobile enterprise assets enables informed decision-making and offers improvements for productivity, safety and security. Such kind of Mobile Asset Management Systems (MAMS) [3] has generated significant interest from manufacturing organizations desiring more efficient methods in managing their asset fleets through total asset visibility [8].

3. Technology and Implementation

The RTLS system developed uses three kinds of wireless devices: the active RFID tag, the Router and the Gateway. Active RFID tags are designed for fixing on different types of objects/assets (wearable tags for humans) and can be used for tracking objects as well 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 router 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.

Routers can be used for range extension of the active RFID devices. In real-time location systems, 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 with respect to the fixed routers.

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.

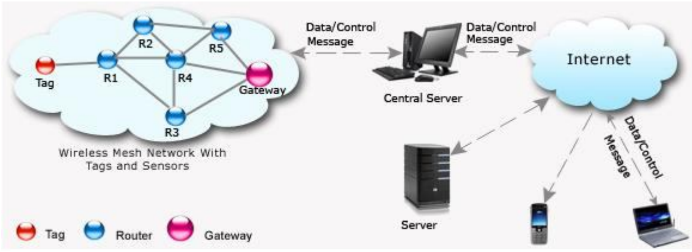

Fig. 1: Wireless Mesh Network system architecture

An important aspect of the wireless mesh network is to develop an efficient route to multi-hop the data packet from the tag to the sink (or gateway). The ZigBee Stack [12] supports the hierarchical (denoted as C_{skip}) and Ad hoc On Demand Distance Vector (AODV) based routing. Our implementation used a variation of the hierarchical network where node addresses are made once the network is in place. The addressing follows a depth first approach where the first address is given to the leaf of the network and works upwards towards the root. The addressing algorithm is akin to the C_{skip} in the sense of addressing in the depth first approach. However, C_{skip} assumes the worst case and would earmark addresses for non-existent nodes. This leads to a huge amount of address wastage and this precisely is avoided in the static algorithm. The detailed description of the routing algorithm can be found in the authors' previous work in [2].

The algorithms are implemented on Chipcon's CC2430 wireless devices and use the IEEE 802.15.4 MAC implementation by TI (TIMAC). The wireless devices are housed in weather proof cases with capability of being both mains and battery powered. We limit the technical details of the implementation as the primary focus of this paper is on the deployment experience and value created by an RTLS system.

4. Deployment of the RTLS System

The assets to be monitored are fork-lift-trucks which move in the factory premises carrying processed goods from the production tool to the warehouse. The factory operates on a round the clock fashion with three shifts, each of eight hours duration. The factory area is around 500 square meters and a total of 13 wireless routers were placed to have a complete wireless coverage and track the location of the trucks at strategic points. A total of 9 trucks were monitored round the clock for a period of over 100 hours. Figure 2(a) shows the placement of a wireless router and figure 2(b) shows a FLT tagged with the wireless tracking device.

Fig. 2(a). Placement of a mesh router; 2(b). Tagged FLT.

An initial study of the energy in the ISM band all along the factory premises was made. The energy is a measure of how much interference can be expected. Also, concerns of the wireless system interfering with the normal working of the production facility can be evaluated. We measured the energy before deploying the RTLS system at 20 locations in the factory and for the entire spectrum of 2.4000 to 2.4835 GHz (Fig. 3 a&b). This band corresponds to the 18 channels of communication as stipulated in the IEEE 802.15.4 standard. The energy is found to be significantly low and interference in any of the bands would be non-existent. The energy measured corresponds to only about 20% of the maximum energy possible. Across the entire spectrum of the 18 channels, some energy in the band was found in the administration building and in the vicinity of the primary production tool (Fig. 3b). This could be due to the Bluetooth/Wi-Fi enabled phones of the personnel in the region. However, this measured energy was limited to only particular channels of the spectrum. In particular, even in the administration and production tool areas, the channels in the latter half of the spectrum were completely devoid of any interference. We appropriately chose the channel that has no interference for our system. Through this, we can conclude that the ISM band used in the IEEE 802.15.4 standard is extremely non-invasive and can be successfully used for wireless communication in this particular manufacturing facility.

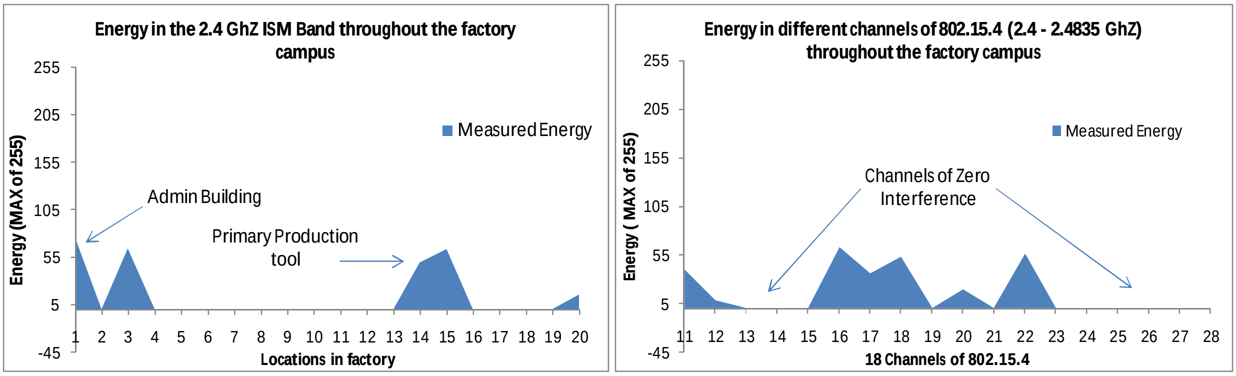

Fig. 3(a). The measured energy is an indication of interference; 3(b). Zero interference expected in multiple channels.

Having set up physically the tags and the routers, we configure a software GUI which pictorially depicts the locations of the various assets in real-time. The GUI is shown in Fig 4.

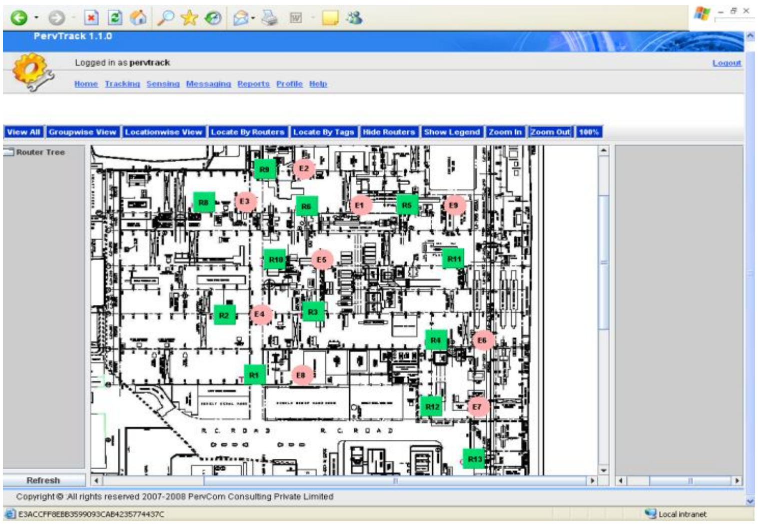

Fig. 4. Zone-wise real-time location tracking GUI

The data obtained from the wireless mesh network is primarily stored in different staging tables in a central server database and subsequently processed and analyzed by the software to get a real-time view and status of the tracking and monitoring zone. We now present the analysis of the transactional data obtained, the optimization problem developed and the value generated from an RTLS system.

5. Results and Analysis

A total of 9 mobile assets were tagged to be tracked. The system records the amount of time an asset spends staying stationary at a particular location. The asset utilization rate is then calculated as:

$$Utilization\ Rate(\%) = \frac{Amount\ of\ time\ spent\ active}{(Amount\ of\ time\ spent\ idle) + (Amount\ of\ time\ spent\ active)}$$

We term the asset as idle, if it spends more than 5 minutes at a particular location continuously. We also calculated the utilization rate with a 10 minute idle time. The utilization rates do not include the time spent by the asset charging its batteries, i.e. the calculated rates are once the asset is in commission. The utilization rates varied from 14% to 59% for a 5 minute idle time and from 22% to 76% for a 10 minute idle time (Fig 5). The aggregate efficiency comes to 50% for a 10 minute interval and 38% for a 5 minute interval.

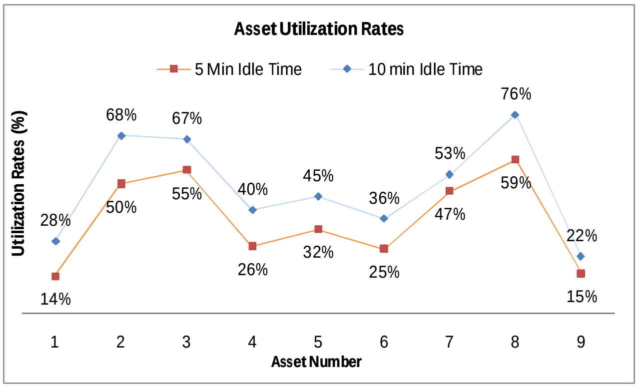

Fig. 5. The asset utilization rates for the 9 tracked assets.

We, now, look closely at asset 1, which has the least utilization rate. Its activity chart, which is a plot of the duration of time spent at every location, is shown in Fig 6 (a & b). Notice that the asset is intensely used for large periods of time, but when idle, it is unused for a very long duration. This indicates, the asset once used is parked and is removed for use only when needed thus giving a utilization rate of 14% for a 5 minute idle period. This throws up the question on the reason for the disuse of the asset, which needs to be further investigated. We suspect the asset to belong to a particular class of vehicle that needs a special skill or favoritism and forceful exclusivity by the drivers. Having details on the utilization directs our attention to look deeper at particular bottlenecks.

A breakup of the utilization rates for the 10 minute interval into night and day was made. Day was considered from 8 a.m. to 8 p.m. and the rest as night. Except for 2 assets (5 & 7) all the others showed better utilization during the night (Fig. 6 b). This brings up questions on the managerial effectiveness and the incentive schemes for the two periods.

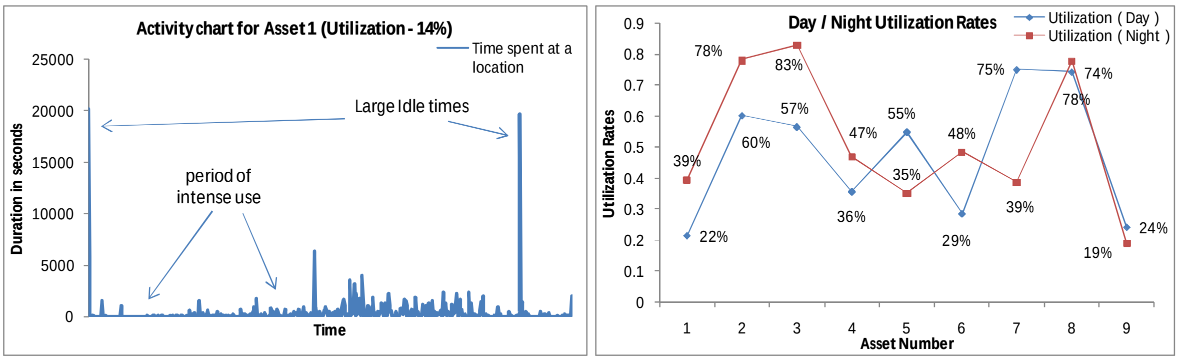

Fig. 6(a). Activity chart showing large periods of inactivity; 6(b). The Utilization rates divided between day and night shows night time efficiency is generally better.

5.1. Theoretically Achievable Efficiency

We now look to determine the number of assets needed to cater to the observed activity. To optimize the number of assets required, we first formulate the problem as follows. The time unit is divided into units of 10 minutes (or any other desired granularity). Subsequently, for each unit of time the assets that are active are marked. This can be represented in matrix notation as shown below. The number of time units is represented as‘t’ and shown along the rows. The number of jobs (activities) is represented as ‘n’ and is shown along the columns.

$$Activity\ Chart, A_{nt} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & \cdots & a_{1t} \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & \cdots & a_{2t} \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdots & a_{3t} \\ 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & \cdots & a_{4t} \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & \cdots & a_{5t} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & a_{6t} \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & \cdots & a_{7t} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & a_{n6} & a_{n7} & a_{n8} & a_{n9} & \cdots & a_{nt} \end{bmatrix}$$

Then, the number of assets in use at a given time can be calculated as the sum of the corresponding column (eqn 1).

$$Num\ of\ Assests_t = \sum_{i=1}^{i=n} a_{it} \tag{1}$$

The maximum achievable efficiency for a given mobility pattern when the maximum number of assets is procured is then given by:

$$Max\ Efficiency = \frac{\sum_{j=1}^{j=t}\sum_{i=1}^{i=n} a_{ij}}{t * \max\left\{\sum_{i=1}^{i=n} a_{ij}\ \forall j = 1,2,3..t\right\}} \tag{2}$$

A plot of eqn (2) is shown in Fig 9. It represents the number of assets that are mobile simultaneously at a given time. We note there are a number of instances where all of the 9 assets are in simultaneous usage. Thus, if we wish to have all 9 assets commissioned, then the maximum efficiency according to eqn (2) comes to 53.8 %. Theoretically, this value must be the same as the aggregate efficiency calculated earlier as 50%.The slight discrepancy is due to our time slice window. We have considered the time units in chunks of 10 minutes. When the time unit is taken as a second, we would get the earlier calculated value (of 50%). Another interesting aspect is the apparently low number of assets used during the latter part of the timeline. This is due to the holiday in the factory premises for one day during the period under consideration.

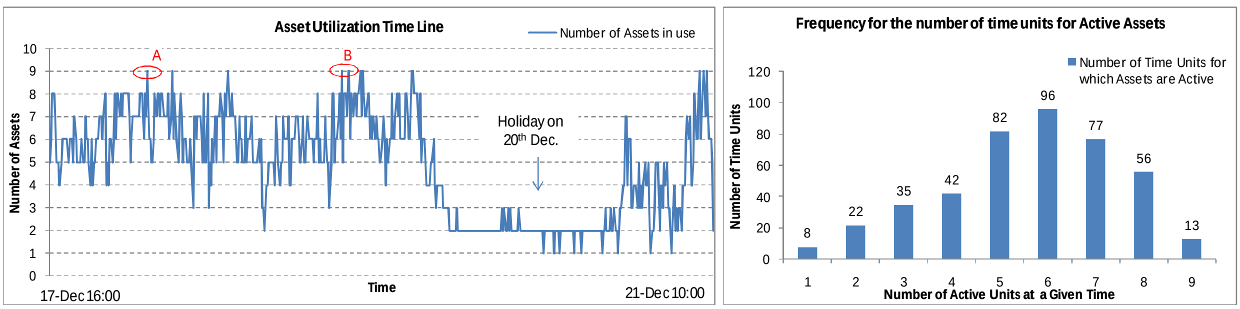

Fig. 7(a). Plot of the number of assets used over the tracking period. Number of instances of maximum usage (all 9 assets) at Points A, B; 7(b). Plot of the cumulative frequency of the number of assets used, the cumulative frequency follows a bell curve.

A plot of the cumulative frequency of the number of FLTs used over time (figure 7 a & b) shows a clear bell curve distribution with 6 FLTs active most of the time. However, number of assets from 5 to 7 forms the bulk of the usage indicating the ideal optimal would lie in these number of assets.

5.2. Closed- Loop Control

Based on the utilization ratio of the tracked FLTs, we have incorporated a closed-loop control mechanism to improve their utilization on a real-time basis.

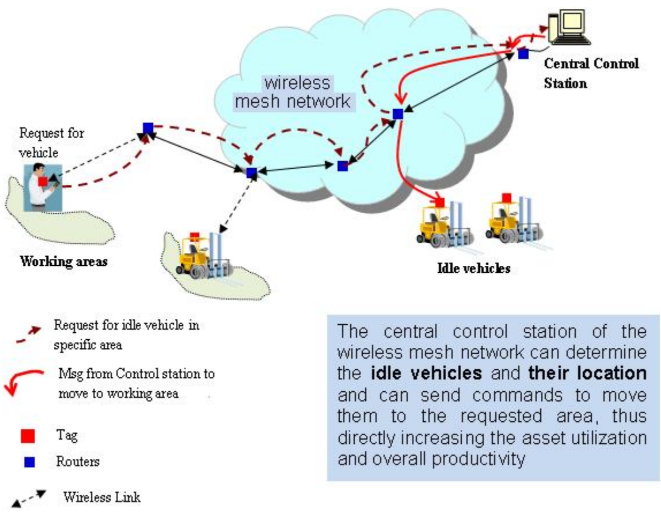

Fig. 8. The closed-loop control mechanism for improving the asset utilization by allocating idle vehicles to the requested working area

In this mechanism, as depicted in Fig 8, a supervisor working in the factory floor could request for a FLT if he sees the need. The request from the factory supervisor is analyzed at the central control station where based on the real time utilization data the system identifies the most idle FLT and sends a command to move towards the requested area.

However, this allocation mechanism could be further optimized by analyzing the production process at the factory floor thoroughly. The production area is zone wise segregated according to the nature of work in particular areas, and group of defined FLTs are allocated to cater to that particular zone. The relative proximity of the idle vehicles is an essential criterion for allocation. It leads to path minimization technique which essentially saves on the energy cost.

Since the industries mostly deal with very high-value mobile assets, therefore, these real-time observations on asset utilization helps the management to streamline their operational process, cut down their capital expenditure as well as maintenance cost to a great extent. The RoI on this new technology is thus visible to the management at once.

6. Conclusion

In this paper we have demonstrated the ability of tracking mobile assets and establishing accurately their utilization rate using an IEEE 802.15.4 based RTLS. Recording the physical mobility gives a clear understanding into bottlenecks and the patterns of activity. Our analysis of the movement of Fork-Lift-Trucks has lead to some insights and recommendations. The average utilization was found to be only 38% and the rates for individual assets varied widely from 14% to 60%. Assets that are in use continue to be used while those that are inactive, are used only when the number of concurrent jobs increases. This leads to a non uniform wear and tear of the assets which in the long run can lead to larger maintenance costs. The night time utilization was found to be generally higher than the corresponding rates for daytime. Using the mobility pattern we have devised the theoretically achievable efficiency and the optimal number of assets required. We have also shown the real-time utilization improvement through a closed loop control.

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