Application of 6LoWPAN for the Real-Time Positioning of Manufacturing Assets

Jaacán Martinez and José L. M. Lastra
Tampere University of Technology
jaacan.martinez@tut.fi and jose.lastra@tut.fi

***Abstract* – In the last decade positioning of assets in a manufacturing industry has become one of the milestones in the process to increase the insight visibility and improve the manufacturing practices. The mobility of the assets in a factory makes necessary the use wireless sensor networks, but in order to avoid an increase of the complexity as well as increase of the cost the assets have to interact with a common network protocol. 6LoWPAN adaptation layer offers the needed mechanism for adapting an 802.15.4 wireless sensor network to working with IPv6 protocol. This adaptation layer has allowed the development of a real-time positioning of manufacturing assets application using a 802.15.4 compliant wireless sensor network and taking advantage of the features offered by the IPv6 protocol. The positioning approach involves the implementation of SDS-TWR technique; however key needs of the used positioning approach cannot be fulfilled with the current IP routing mechanisms. IP routing has no control over network topology and the required link for positioning between a tag node and at least three anchor nodes cannot be guaranteed. This paper explores the possibility of modifications in routing mechanisms in order to minimize unnecessary interactions accordingly to the implemented application.**

I. INTRODUCTION

Nowadays the manufacturing industry is facing a high competitive scenario in a world where the market has been moving from being supplier-driven towards a customer-driven market. The industrial capacity has increased as well as the customers demand for higher quality, cheaper and wider variety of products, making the improvement of efficiency together with cost reduction tasks to play a key role in the business success [1].

The lack of real-time information in the traditional manufacturing process has lead to practices that add unnecessary costs to the production cycle such as scheduling delays, time wasted in manual activities (e.g. searches, inventory checks), greater risk of violations of safety protocols, inefficient allocation of equipment, parts and personnel, inefficient maintenance scheduling, among others. Challenges faced by manufacturing industry in the last decade have made of such a great importance the necessity of having a clearer view of the entire manufacturing process all along the supply chain. The development and implementation of systems to trace the whole history of the product aim for a reduction in the product life cycle, time to market, business risks and cost investments while increasing the flexibility and robustness of the supply chain. In manufacturing process, the usage of tracing techniques can be done in three forms: status tracking to detect system status, performance tracing to analyze system performance and goal tracing to support the decision making process, giving the opportunity of following the history of events occurred in the process and compare them with the scheduled plans and predefined goals [2].

In tracking and tracing techniques, information commonly needs to be represented at asset level and shared between different instances in the system. Therefore positioning of assets in a manufacturing industry is one of the milestones in the process to increase the visibility and allow a better management of assets leading to better manufacturing practices [1] by feeding this information to the manufacturing and logistics processes.

II. BACKGROUND

Computers embedded in the physical world make possible the realization of the asset-aware manufacturing schema. The use of smart devices enables the opportunity to provide valuable real-time information to manufacturing processes that help in the decision making process and allows faster responses to cope with disturbances. The ability to react in a fast way to disturbances helps in the optimization of production, the reduction of energy consumption, the reduction of pollution and waste as well as in the improvement of the industrial security [3].

In order to allow the assets equipped with a smart device to communicate each other, interact and exchange information, a suitable wireless network technology has to be implemented [4]. Many ad hoc solutions for low-power wireless networking have been developed in the past years (e.g. ZigBee, Z-Wave, among others) making possible to deploy Wireless Sensor Networks (WSN). However, WSN's that use different proprietary protocols are not able to interact among them unless the use of application gateways at expenses of increasing design and management complexity. The end-to-end communication can be achieved by using a common network protocol working on top of different link technologies (e.g. Wi-Fi, Ethernet, and 802.15.4). The usage of an open standard interface such as Internet Protocol (IP) as the common networking layer provides greater robustness and flexibility to the system [3]. In addition, IP provides transparency for host and servers in the network with no need for using gateways and support unique addressability, seamless connectivity as well as wide applicability [4].

A new Internet Protocol has been developed, the Internet Protocol Version 6 (IPv6) specified in [5] as the successor of the known IPv4. IP addresses are required to be global and unique for each node of the network, satisfying the scenario where networking appliances and assets are expected to outnumber the conventional computer hosts using IPv6. The new protocol offers a space of 128 bits for IP addressing, expanding the 32 bits offered by IPv4. Moreover, IPv6 increases the Maximum Transmission Unit (MTU) to 1280 bytes, unlike IPv4 MTU of 576 bytes. In order to increase performance and simplify routers the fragmentation is performed at endpoints (preferably than in intermediate routers). Also, IPv6 includes link-local scoped multicast for bootstrapping such as Neighbor Discovery (ND), duplicate address detection (DAD) and router discovery [6].

Despite IPv6 was meant for nodes with higher capability, it suites better than IPv4 to cope with the needs of WSN's because of the inclusion of the bootstrapping functionality, the support for options and the ability for adapting different link technologies. Moreover, the new protocol supports stateless address auto-configuration and the large IP address allows performing cross-layer compression and the utilization of mechanism widely used in wireless sensor networking [3].

However WSN's utilizes Wireless Personal Area Networks (WPAN) technologies, designed for working with low-power consumption. For instance, the IEEE802.15.4 standard specifies the physical and MAC layer of a WPAN for low cost, portable Wireless Network Access Technology for fixed or mobile devices that are easy to use and ease to embed, but running at low-rate. IEEE802.15.4 supports data rates of 20, 40, 100 and 250 kbps, running at 868/915 MHz and 250 kbps at 2450 MHz and is suitable for short distances from 10 to 100 meters, carrying information on radio transceivers at a frequency band close to Wi-Fi but about 1% of the power consumed by Wi-Fi and with a maximum frame size of 127 bytes, out of them 102 bytes are for payload due to the 25 bytes required by MAC headers at most [7].

The resource constrains defined by the nature of the low-powered devices, make impossible the straight forward implementation of IPv6 protocol in them, therefore the usage of an adaptation layer is needed triggering the development of the IPv6 over low-power wireless personal area networks adaptation layer as known as 6LoWPAN. This adaptation layer works on top of physical and MAC layers, defining how IPv6 datagrams are transmitted using 802.15.4 frames by implementing compression/decompression of IPv6 headers, assuming common values and eliding them when they can be derived from link-layer information over the 802.15.4 or making assumptions based on communication context information. In addition, IPv6 packets might be fragmented/ defragmented to make the minimum MTU requirement to fit into link-level frames. 6LoWPAN also supports layer-two (MAC) forwarding of IPv6 datagrams, but using stateless or shared-context compression to elide adaptation, network and transport layer fields helps in the reduction of the length of each datagram [8]. Another important aspect which 6LoWPAN adaptation layer has to deal with is the time-varying link relationship among the nodes comprising the WSN. It has to support implementation of routing protocols at either link layer (mesh under routing) or network layer (route over routing). Mesh under approach implements no IP routing within the WSN by routing and forwarding packets over multiple radio hops looking for emulation of a local multicast and avoiding obstructions. Route over approach performs IP routing, using each node as an IP router, supports three forwarding mechanism within the WSN allowing the use of network layer capabilities such as IPv6 routing and ICMPv6 for configuration and management [6].

Using 6LoWPAN adaptation layer makes possible the deployment a IPv6 low-power wireless personal area network, providing internet connectivity to low-powered devices that can be embedded in industrial assets for gathering information that allows the improvement of efficiency and cost reductions in manufacturing processes. However a trade-off between power consumption and functionality has to be performed while looking for the maximization of the network potential.

III. REAL-TIME POSITIONING SYSTEM

In a factory expensive assets (e.g. tools and equipment) need to be shared among different parties while others are fixed to certain position, products are moved along the production line and personnel is moving constantly. The mobility of the assets makes a wired based positioning system insufficient, arising the need of the usage of wireless based positioning systems working together with the wired based ones or in an independent way. As mentioned previously, the integration of different technologies requires a common network protocol (e.g. IPv6) to void the increase of complexity of the system and to support the needed mobility while allowing interoperability as well as reliability among different communication protocols [3].

The main objective of an industrial location system for assets is to provide real-time information where integrity of this information, accuracy of positioning computations and latency are the key parameters to be accomplished. In order to implement a real time location system (RTLS) ranging and lateration tasks have to be performed where the position of a mobile node (tag) is computed in relation to a set of fixed or well-known positioned nodes (anchors). In a WSN, ranging tasks can be implemented using different approaches, for instance received signal strength indication, time of arrival, time difference of arrival, angle of arrival, line of sight, time of flight, two way ranging, round trip time, symmetrical double sided – two way ranging (SDS-TWR), near – field electromagnetic ranging, among others [9].

Accordingly to [9] SDS-TWR ranging approach using Chirp Spread Spectrum modulation technology works properly in an industrial environment with accuracies on a plane of ±2.51% and ±5.14% for x and y axes respectively in an area with no divisions. This ranging scheme can be performed in two forms, a synchronous (require global synchronization and precise oscillator) or asynchronous (each node uses its own clock). The main objective of SDS-TWR method is to calculate the time of flight of a message transaction between the nodes of interest. A synchronous approach results in a more expensive solution due to the robustness of the required infrastructure, making a synchronous approach a more reliable solution from the economical point of view. However, since there is no global synchronized clock, three phases has to be implemented: scanning, ranging and reporting. The scanning phase is intended for a tag node to detect an anchor node by sending a message and waiting for an acknowledgement. The ranging phase is comprised by a sequence of packets in order to each node measures the round trip time of a message exchanged as well as its processing time in order to calculate the time of flight. The last phase, reporting consist of sending the information to a server for further positioning computations.

This approach where messages are sent in a sequential manner results in a considerable increase in the traffic over the network and an increment in the power consumption of each device. Considering the application of a location engine based on SDS-TWR technique on an IPv6 enabled WSN altogether with tri-lateration, some shortcomings arise, in addition with the already mentioned increase on the network traffic and power consumption of the devices [10].

A tri-lateration location engine, based on SDS-TWR ranging approach assumes the straight link between a tag and three anchor nodes, resembling a star topology. However, the topology on a 6LoWPAN network is not defined, moreover is a time-varying topology that depends on physical conditions. As mentioned before, 6LoWPAN has to support routing at both levels (MAC and IP) and has to implements the needed mechanisms to allow the link-layer informs the routing as well as informs the layer where the forwarding occurs [6].

The routing mechanisms implemented in a 6LoWPAN do not take control about the formation of the topology of the network, but they just allow the adaptation of the routing topology to the changes in the connections, i.e., the user does not have control over the network topology.

The deployment of a 6LoWPAN WSN cannot guarantee the satisfaction of the need of a straight link between a tag and the anchor nodes required for SDS-TWR methodology. This ranging methodology is based on the measurement estimation of the time of flight and the calculations performed allow the computation of the straight distance between the nodes of interest. The uncertainty of a straight connection between the nodes leads to errors when a direct link is not achieved because the time of flight will not travel in a straight line and nodes in-between will add complexity to the calculations and will increase the power consumption of the system.

In addition, there is no such a way to identify whether a node is an anchor node or a tag, leading to unnecessary message exchange between tags nodes. This identification problem can be solved by defining a header (option) or message for identifying the type of node during bootstrapping, therefore a tag will be able to ignore messages from those nodes who are identified as tags and will be able to consider in their routing table as well as in their neighbor cache only the nodes identified as anchor nodes. Considering that the ratio between anchor and tag nodes decreases as the network size increases, the traffic on the network can be reduced by minimizing the interactions between tags. The limitation of unnecessary interaction helps in the reduction of network collisions while attempts to increase the integrity of the information and to reduce the latency of the system.

IV. TEST BED

The efforts for the development of a real-time positioning system based on a 6LoWPAN Wireless Sensor Network have been done using the ATAVRRZRAVEN 2.4 GHz Evaluation and Starter Kit. This kit contains a set of two AVR Raven boards with a 2.4 GHz transceiver, on-board picoPower AVR application processor with LCD display and one USB stick with 2.4 GHz transceiver [11]. The operating system is ContikiOS version 2.5 release candidate 1[12]. Shortcomings faced so far are the system clock resolution, limiting the accuracy of time of flight calculations and the uncertainty of straight link between the tag and three anchor nodes. Future efforts will be aimed to build a service-enabled positioning system.

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