Agent-Based Factory Level Wireless Local Positioning System With ZigBee Technology

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***Abstract*—Local positioning systems are able to track physical assets or people. Such systems can help, but are not limited to, factory automation, asset management. However, it is not easy to apply such systems at the factory level because they are limited by the challenging environment (e.g., obstacles and hostile environment). Advanced wireless technologies provide a chance to make such applications possible. One of the possible technologies is the ZigBee technology, whereas a brief review of the technology and specification of which is presented in this paper. Since the wireless local positioning systems could be represented as a sensor network, multi-agent system would be a good candidate to model such systems. In this connection, an agent-based wireless local positioning system with ZigBee technology is proposed in this paper. Based on this system, some applications are suggested.**

***Index Terms*—Agent, factory automation, local positioning system, sensors networks.**

I. Introduction

In general, positioning systems can be categorized into three groups, namely, absolute, relative, and local [1]. An example of absolute positioning system is the famous Global Positioning System (GPS). Such system provides an absolute coordinate of an object, which has global coherence of a network. In contrast, relative positioning systems give out the information of an object that is relative to a system, which is local to the network. However, the systems are still able to provide network-wide coherence. Finally, a local positioning system has only local coherence, like a factory, and might be used by the communicating parties who get involved. Local positioning systems aim to track physical assets or people, most often in a confined environment like a factory [2]. The factory level wireless positioning systems fall into this category.

This is not, conceptually, a new idea. However, wireless local position system is relatively a new research area due to the maturity of wireless applications in the last decade, especially in the consumer market [3]. Forno *et al.* [4] stated that wireless indoor positioning systems have become "one of the most challenging services". The reason behind this is that many indoor positioning technologies are limited by the line-of-sight requirement [5], which is a challenging problem in the cluttered and unstructured environment of many real-life applications. A distinctive feature of the "total" wireless counterpart is that it can accomplish the objective within the coverage of the network, which could be a harsh environment that the wired systems are difficult to be installed.

In addition, scalability of wireless systems can boost the system performance since devices could be installed as a "plug-and-play" basis, if a proper addressing system is maintained (analogous to wireless LAN). A typical technique to locate the position of an object is the received-signal strength systems (e.g., [4], [6]). This is based on the propagation-loss of radio signal, which is governed by the inverse square distance, in order to come up with the estimated distance from one source to another. By utilizing the received-signal strength of wireless devices, Forno *et al.* [4] designed a wireless network for indoor positioning applications. In fact, there are various techniques in finding the distance between two objects. Vossiek *et al.* [3] compared a number of principles regarding this measurement. However, the architectural aspects of these positioning systems are generally not well documented. In this connection, this research aims to propose an agent-based factory level local positioning system.

As a matter of fact, a wireless local positioning system is inherently a sensors network. There is a need to coordinate the sensors because they are actually loosely coupled devices, which could move freely in the network so that the possible combination (in terms of location tracking) is not predictable. This is also the rationale behind the fact that agent-based system is proposed to model such systems, as coordination among agents is one of the major advantages of multi-agent systems [7], [8]. In this connection, the major objective of this paper is to propose an agent-based system, with ZigBee wireless technology, for local positioning systems, which focus on factory level applications. The rest of this paper is organized as follows: Section II provides a review of the multi-agent systems and the ZigBee technology. Section III presents the proposed system while Section IV discusses the applications of the proposed system, and is the concluding section.

II. Review of Multi-Agent Systems and the ZigBee Technology

A. Multi-Agent Systems

Research in "Multi-Agent Systems" is a prevalent topic in the last two decades in many areas. It is a branch of artificial intelligence called distributed artificial intelligence, which attempts to compensate for the deficiencies of classical Artificial Intelligence with regard to the development of intelligent agent. An agent can be defined as "a computer system, situated in some environment that is capable of flexible autonomous action in order to meet its design objectives" [8]. In a multi-agent system, a number of heterogeneous agents are working independently,

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or in a cooperative and interactive manner to solve problems in a decentralized environment.

There are number of factors that make agent-based approach applicable as follows (they are extracted from Wooldridge [9]).

i) Open Environment, or at least highly dynamic, uncertain, or complex environment – In such environments, systems capable of flexible autonomous action are often the only solution.
ii) Agents are a natural metaphor – Many environments are naturally modeled as societies of agents, either cooperating with each other to solve complex problems, or else competing with one another.
iii) Distribution of data, control or expertise – In some environment, the distribution of either data, control, or expertise means that a centralized solution is at best extremely difficult or at worst impossible. Such systems may often be conveniently modeled as multi-agent systems.
iv) Legacy systems – Some software cannot generally be discarded, because of the short-term cost of rewriting. And yet it is often required to interact with other software components, which were never imagined by the original designers. One solution to this problem is to wrap the legacy components, providing them with an 'agent layer' functionality, enabling them to communicate and cooperate with other software components.

The main characteristics of an agent, by definition, are that it is reactive, goal-oriented, able to learn, autonomous, mobile, and able to communicate with other agents [7]. It was suggested in Wooldridge and Jennings [10] that an agent should possess the following capabilities.

i) Autonomy – agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;
ii) Reactivity – Agents are able to sensing the changes that occur in the environment, and response accordingly in order to satisfy their design objectives;
iii) Proactiveness – Agents' behavior are driven by the goal(s) of the system;
iv) Social ability – Agents are able to communicate and interact with other agents in order to achieve the goal(s) of the system.

Mobile agents are specialized agents that are not bound to the system where they begin execution but are free to travel through a network [11]. This distinctive feature enables mobile agents to transport freely from one system to another. Mobile agents can "move locally to the resources (they) need, instead of requiring either the transfer of possibly large amounts of data or a huge network" [12]. A key issue that hinders mobile agent applications and needs to be addressed for mobile agent systems is administrability of mobile agent systems through, for example, authorization policies [13]. Since a mobile agent can move freely in a system to interact with any other agents, it can obtain information on a local knowledge source without network communication [14]. An example of agent-based location tracking systems was presented by Satoh [15].

Based on factors influencing the applicability of multi-agent systems as discussed above, it is easy to envisage that local positioning systems can be implemented as multi-agent systems.

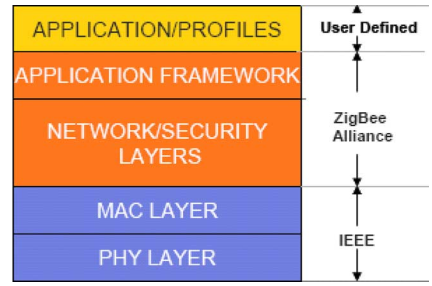

Fig. 1. Open structure of the ZigBee Standard (Source: ZigBee Alliance [18]).

The next question, however, is that why do we need the aforementioned characteristics of multi-agent systems for local positioning systems. This is also the research motivation of this paper. As a matter of fact, one problem of typical local positioning systems is that the environment is uncertain so that devices in such systems may not be able to react intelligently based on the real-time external information. For example, one method to determine the position of a device as mentioned in previous section is to use the signal strength of the devices relative to some signposts. In agent-based systems, the accuracy in doing this can be enhanced without increasing the number of fixed signposts because a society of agents is formed and the relative location can be visualized by considering the mobile agents as additional signposts. In addition to this, more intelligent coordination mechanism can be developed for value-added services based on the coordination and communication capability of the agent-based systems.

B. *ZigBee Technology*

Most factory communications across a number of entities are short-range, and transmission of which is preferably through wireless media [16]. ZigBee, which is built on the physical and MAC layer standard IEEE 802.15.4, defines the application and security layer specification [17]. Fig. 1 depicts the open structure of the technology, which is promoted by the ZigBee Alliance. ZigBee can be applied in a variety of applications of interoperable consumer devices which are low cost and low power in principles, and the technology is one of the short-range wireless alternatives suitable for factory-level communications. A ZigBee network consists of three types of devices, namely, ZigBee Router, ZigBee Coordinator, and ZigBee End Device.

i) ZigBee Router: It performs like a router or repeater. It is a channel for packets traveling from their source to their destination.
ii) ZigBee Coordinator: It is a special type of router, with special network management functions. It is responsible for forming the network, setting up an addressing scheme, and maintaining all routing tables and bindings for the network.
iii) ZigBee End Device: It is neither a ZigBee Router nor a ZigBee Coordinator. It is set as sleep mode when it is idle in order to lowering its power consumption.

ZigBee is a cost effective solution for low-power industrial monitoring control applications. The low-power attribute partly due to its low data transfer rate (up to 250 kb/s only) over a range of 10 to 100 meters. Obviously, this is not suitable for applications that involve transmission of massive data like video files. However, this limitation is virtually not a problem for most industrial applications, like the proposed local positioning systems. More importantly, the benefits that are originated from the strengths of the technology can certainly compensate its weaknesses. The benefits of the technology are summarized as follows ([17], [19], [20]).

a) First of all, the technology supports full mesh network. Therefore, transmission path is not fixed and hence flexible transmission path is possible so that even in harsh factory environment, adoption of the ZigBee-based wireless system is much more viable.
b) Secondly, the technology can support up to 16-bit address and each device is assigned a unique address, which means more than 65 000 devices, or nodes, could be installed in a dedicated network.
c) More importantly, the technology adopts 128-bit Advanced Encryption Standard cryptography, with keys delivered to joining nodes by a trust center. Therefore, security level of the system could be enhanced as compared with some existing wireless systems. Therefore, transmission accuracy is robust.
d) ZigBee makes use of the unlicensed industrial, scientific, and medial band (ISM). It includes 2.4 GHz, 868 MHz (mainly for Europe), and 915 MHz (mainly for the U.S.). Therefore, there is no investment in applying for frequency spectrum.
e) Last but not least, low power consumption as discussed before makes battery operation possible.

Selection of wireless technology for factory level applications is influenced by two major factors: accuracy (i.e., robustness and security) and power consumption ([19], [21]). From the list above [more specifically, (iii) and (v)], ZigBee fulfils both criteria. Therefore, ZigBee is an appropriate, if not the best, candidate in implementing the proposed agent-based system that will be discussed later.

C. Other Wireless Alternatives

It is not surprising that a particular technology cannot cater for all applications in different scenarios. There exists other wireless alternatives in the field and this section dedicates to explain why ZigBee is proposed in this paper, with reference to the features of ZigBee as discussed above. It is not the intention of this paper to examine all wireless alternatives. Thus, focus is put on those technologies which are closely related to local positioning systems only. Comparison is made according to three aspects: (i) other wireless network standards; (ii) other alternatives of the IEEE 802.15.4 standard; and (iii) other wireless alternatives like the Radio Frequency Identification (RFID) technology.

One distinctive feature of the IEEE 802.15.4 is low power consumption due to low transfer rate. In this connection, the positioning of this standard is different from other counterpart (e.g., IEEE 802.11 or Wi-Fi [22], IEEE 802.15.1 for Bluetooth, etc.). This low-power feature creates a unique application segments for the ZigBee technology (or IEEE 802.15.4 in general). In addition to this, IEEE 802.15.4 (and hence ZigBee) allows mesh network configuration, which is flexible to cover wider areas with unexpected obstructions which could interfere the transmission of radio signal [23]. In addition, each device is assigned with individual address, which is analogous to IP address for Internet applications [24]. This feature enhances the applicability of control and monitoring applications (like the locating systems in this paper). In contrast to other master-and-slave network (like Bluetooth), this configuration can create synergy with multi-agent systems. For example, in a positioning system, each device could be equipped with certain degree of autonomy to determine their location based on local coordination, on top of the global location tracking based on traditional technique.

In particular, ZigBee and Wi-Fi have their own distinct application requirements. Advantages of ZigBee on cost, power consumption, network structure (more than 65 000 nodes) over Wi-Fi means that the latter cannot complete with what the former can offer, whereas ZigBee's bandwidth limits its ability to transmit large data flows as WiFi can handle ([25], [26]). A more detail comparison between ZigBee and Wi-Fi (and also some other alternatives) can be found in Lee *et al.* [25] and Sidhu *et al.* [26].

In recent years, RFID has created a lot of expectations in supply chain and logistics applications ([27], [28]). In fact, RFID is a generic name of a more general class of systems called Automatic Identification and Data Capture, which is the "identification and/or direct collection of data into a microprocessor controlled device without the use of a keyboard" [29]. In general RFID systems consist of two main components: tags and readers, and sometimes a host information system [30]. RFID tags can be further divided into passive tags, which do not need a power source for operations, and active tags, which are equipped with external power sources. However, RFID alone may not be capable to deliver the location tracking feature. Active tags are needed in doing so (e.g., [6] and [31]). In recent years, RFID is coupled with other devices that use radio signal to automatically identify individual items to perform location tracking. For example, Ergen *et al.* [6] proposed a GPS-based RFID system for tracking and locating concrete components in a manufacturer's storage yard. The GPS system provides a coarse idea of the position of the items to be tracked and the active RFID tags, which are used to fine tune the position to achieve a better accuracy. In conclusion, RFID alone is not possible to implement as a location tracking systems, partly because of the design of this technology does not cater for this specific need. In other words, the ZigBee technology (or similar alternatives) can be used to implement such systems, regardless of cost issue because passive tags are needed in the low-cost version of RFID systems. In addition to this, inter-operability of ZigBee-based systems is better than the RFID counterpart.

III. Proposed Agent-Based System

As shown in Fig. 2, the proposed system mainly consists of four types of agents: Console Agent, Router Agents, Device Agent, which is further developed into Paging Agent and ID Agent; whereas some of them are mobile agents. The definition of each agent and its functionality are discussed below.

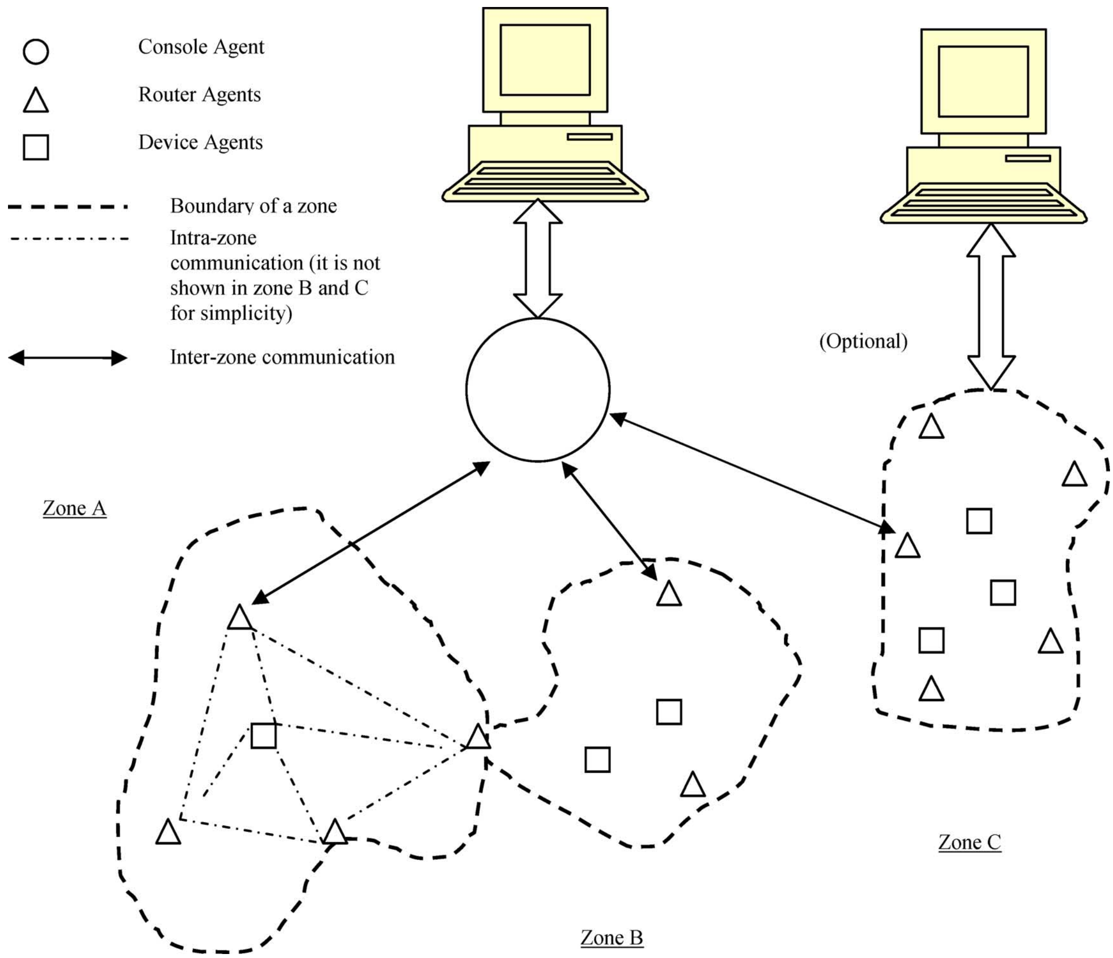

Fig. 2. Architecture of the proposed system.

A. Console Agent

There is only one Console Agent, which is placed at the top of the hierarchy, in a system. The Console Agent takes an administrative responsibility for keeping a macro view of the network information, like number of subscribers to the network, number of zones in a system for paging purpose, etc. In other words, it is responsible for registering new devices, and removal of invalid devices from a master list. Obviously, it would be better if the Console Agent is connected to a Personal Computer (PC) to perform such tasks, as shown in Fig. 2. It is the responsibility of the Console Agent (possibly with the help of a PC) to define the zones.

A directory could then be built up for valid devices which are eligible to present in the systems. This also allows the Console Agent to alert the administrator if invalid devices (like a people who have been laid off) enter the system. Therefore, the Console Agent could be made as an USB device for PC connection. In addition, some application packages could be developed for other innovative applications. For example, if the local positioning system is mainly for paging people in a factory, it could be further upgraded as a payroll system.

The Console Agent is also responsible for sending message to the fixed Router Agents (to be discussed) in order to request the local information of the zones that under their coverage. The Console Agent is the sole agent in the system which can gather all local information to form a full picture of the system. Other Router Agents are responsible for handling the local information within the zone under their coverage. This is primary to reduce communication traffic, rather than to protect sensitive information. In fact, this decomposition scheme is also a characteristic of the agent-based system as discussed in Section II. Whether the overall picture (at a particular time instance) could be shared to all agents or not is specified by the system designers. However, this could be done in the proposed system from the technical point of view.

B. Router Agent

The Router Agents divided the whole network into a number of sub-networks, which is referred to as zones (e.g., there are three zones in Fig. 2). Although the Router Agents are communicating with the agents within a zone more frequently, each Router Agent will also communicate with other agents, especially the Console Agent, if it is necessary. Please note that communication could be gone through some agents as the whole network is a mesh network, as ZigBee can offer.

Normally, at least three fixed Router Agents are required to form a zone, like zone B in Fig. 2. However, the actual number of fixed routers per zone depends on the environment (like zone A and zone C in Fig. 2). A particular fixed Router Agent could be a member in forming two zones, like the one between zone A and zone B in Fig. 2. In other words, the zones can be overlapped. Careful assignment of such Router Agents can reduce system resources since the number of Router Agents can be reduced.

Within a zone, the Router Agents are responsible to find out the position of each Device Agent (to be discussed) under monitor by some measuring principles, like the received-signal strength as discussed in the introduction. A relative position of the agents in the zone are recorded and kept by the fixed Router Agents. This forms a "floor plan" of the zone (this could be displayed visually through a PC if the Router Agents are upgraded with PC interface, as shown in Fig. 2). The frequency to update this floor plan depends on the applications. If the system is to track moving objects, the floor plan should be updated more frequently. On the other hand, if the system is an asset management system which does not involve moving objects, or the objects are not moving so often, the frequency to update the floor plan could be reduced in order to save power consumption. This local information is sent out only if a request is received from the Console Agent, so that a master floor plan could be generated, or for other enquiries that may come across.

In general, more fixed Router Agents are needed if the precision requirement of the position information is high. The precision requirement depends on the system requirement. For example, if the system is to track people in a particular area of a zone, then the precision requirement may not be so tight. However, if the purpose is to find a pallet of inventory from a number of racks, then, more Router Agents are needed.

Once a Device Agent (to be discussed below) enters a particular zone, it becomes a Router Agent in that zone. It can help in conveying messages within the network. However, this "ad hoc" Router Agent is not a fixed device which means it is not responsible for forming a zone.

C. Device Agent

There are two kinds of Device Agent, namely Pager Agent and ID Agent. They are, in principle, mobile agents as discussed in Section II. The difference between these two agents is that the former is an active agent which can send and receive messages in the network autonomously as they need. On the contrary, the ID Agents only act as a passive router and could not send message by itself. Therefore, a Pager Agent is a superset of an ID Agent.

From software development point of view, the two Device Agents are the same, with some functions being disabled in the ID Agents. However, the definition allows for different applications. For example, if the system is a people tracking system, the Pager Agent could be kept by a supervisor who wants to find his/her subordinates that are carrying the ID Agent. It is desired that if these two devices could be made in a wearable form (like a badge) which integrates the antenna and associated electronics including display for the Pager Agents. Alternatively, the Pager Agents can include a USB interface so that the display functions could be done in a PC.

It is also recommended that each zone is connected to a PC through a Router Agent so some positioning applications could be done easily. For example, a floor plan can be displayed in each PC with respect to a particular zone while floor plan of other zones could be sent from the computer interface upon request. To accomplish this, one of the Pager Agents could be connected to the PC (through USB interface as discussed, for example).

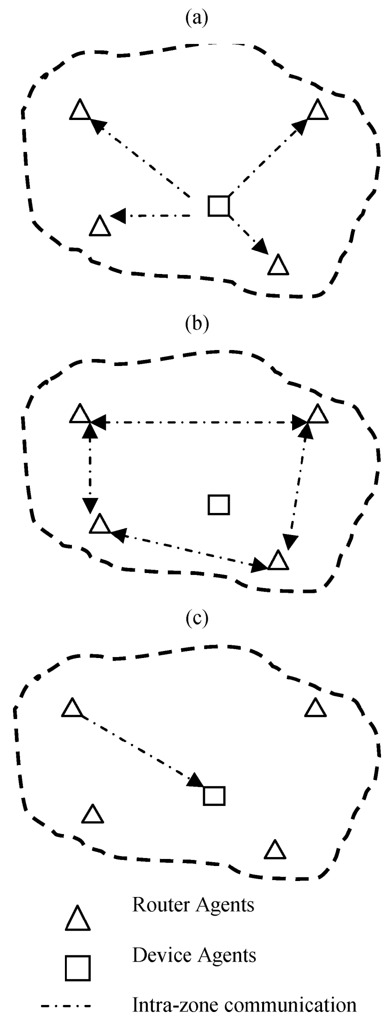

Fig. 3. Intra-zone Communication Mode. (a) Device Agent sends a message to Router Agents. (b) Router Agents coordinate to find a solution. (c) One of the Router Agents replies to the Device Agent.

D. Communication and Coordination

One distinctive feature of the proposed system is that the whole system is divided into a number of zones, while communication within the system could be decomposed into inter-zone and intra-zone communication modes. Figs. 3 and 4 illustrate the two communication modes respectively. This helps to reduce the traffic regarding data transmission. Since each agent is able to act as a node in the mesh network, actual traveling path of data is flexible.

Intra-zone communication mode facilitates the applications that could be resolved within a zone. From Fig. 3, whenever a Device Agent in a zone want to request information from the system (e.g., want to track the location of another Device Agent), it sends a request to all Router Agents in the zone (step (a) in Fig. 3). The Router Agents then coordinate with each other in order to come up with an "answer" and to decide which Router Agent will reply to the Device Agent (steps (b) and (c) in Fig. 3). Intra-zone communication mode can be initiated by one of the Routers Agents as well.

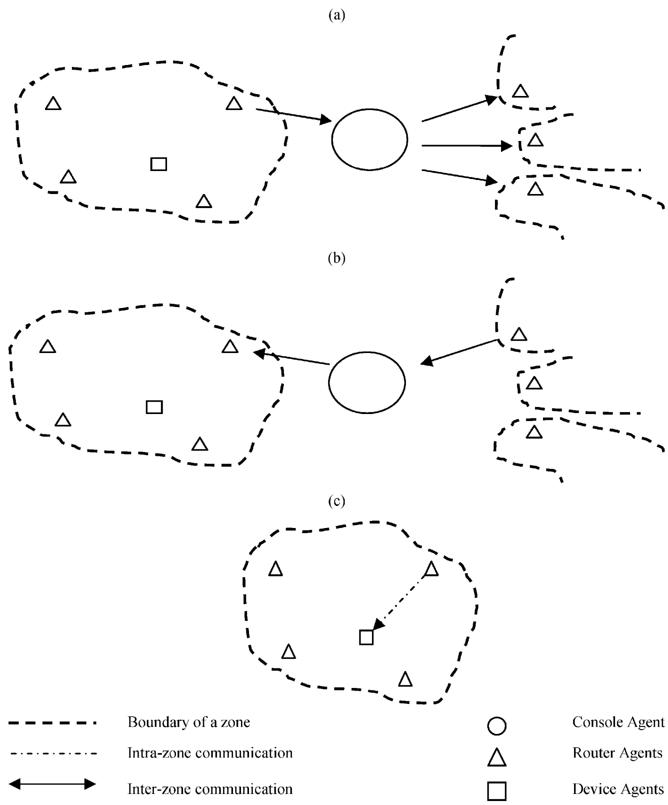

Fig. 4. Inter-zone Communication Mode. (a) Device Agent sends a message to the Console Agent, which relays the message to Router Agents in other zones. (b) One of the Router Agents replies to the Console Agent, which relays the "answer" to the requester. (c) One of the Router Agents replies to the Device Agent.

Inter-zone communication mode is more complicated than the intra-zone counterpart. However, the first two steps are the same as in the intra-zone communication mode (i.e., (a) and (b) in Fig. 3), they are not shown in Fig. 4. Consider the above example if the other Device Agent is not located in the same zone as the requester, the Router Agents, which cannot come up with the "answer", then send a message to the Console Agent as step (a) in Fig. 4. The Console Agent then broadcasts the request to other Router Agents in different zones. One of the Router Agents should be able to provide the "answer". Then, that agent will give a reply to the Console Agent (step (b) in Fig. 4), which then relays the "answer" to the Router Agent that initiates the dialogue. Like the case in the intra-zone communication mode, one of the Router Agents will reply to the requester (step (c) in Fig. 4).

Above example only illustrates a one-cycle communication. In fact, multi-cycle communication could be possible with different applications. However, one issue has not been addressed in this research is that if multiple requests are received, how should the agents prioritize them? This is a multi-objective decision-making problem that is highly dependent on the applications, which is out of the scope of this research.

IV. Discussion and Conclusions

This section provides some insights on how the proposed system could be applied in some real-life applications, followed by the concluding section.

A. Asset or Inventory Management

Consider if the Device Agents are attached in some inventory or assets, the proposed system is in fact an asset or inventory management system which can track the movement of the agents. This is particularly useful if the environment is a large area. For example, the proposed system would be useful in large conferences or exhibitions for tracking valuable equipments. In a factory, the Device Agents could be attached to some equipment in a reconfigurable manufacturing cell, for example, so that the cell configuration could be checked automatically. This could aid intelligent factory planning in the sense that the actual configuration of the manufacturing system is tracked before a change is made.

In fact, potential applications are not limited to tracking physical assets. The principle could be applied to quality management system, which needs to keep track of a certain numbers of valid documents, so that maintenance of the system can be done electronically. Each Device Agent represents a particular set of documents and would be deleted from the system by the Console Agent if it is outdated. In addition, the Console Agent is able to track how many copies of the outdated document are presented in the system. Valid work instructions on the shop floor could be checked remotely so that quality assurance could be improved because correct work instructions are put in place.

B. Staff Paging System

One possible application of the proposed system is local pager system. Consider a supervisor who wants to find a staff that cannot be reached by telephone, the system can report the location of the staff (either in which zone or in which area of a zone, depending on the specification of the system) to the supervisor. With a simple display in the Device Agent, the system is in fact a local pager system that can convey messages from one agent to another one. Although the data rate of the ZigBee technology is not high, transmission of voice data is still possible so that the system could even be deployed as a voice paging system.

If the system is applied in some industrial systems, like mining systems with harsh environment so that wiring is impractical, if not impossible, the wireless system is helpful in identifying the workers in the mine, or to convey messages among them. This could be done because each of which could be a router for conveying messages. To further improve the system, only a number of fixed Routers Agents are required.

C. Factory Automation

Consider if a Device Agent represents an automated guided vehicle, or a robot, then, factory automation could be tracked by the system. More sophisticated automation program or algorithm could be deployed. In addition, the system can also guarantee a certain batches of work-in-process will undergo a certain manufacturing processes since the movement of them is under monitor. This could be done even if a process is in isolated and enclosed area because a zone can be setup in that area and the devices can re-enter the network system after the process is completed and hence data could be sent afterward.

D. Conclusions

More wireless applications have been deploying in the market thanks to the development in wireless technology in recent years, it is foreseen that wireless technology will play a vital role in many application areas that are not possible in the past. Wireless local position system would be one of them. In the literature, reported research is more focusing on the measuring techniques to find the position of an object in the system. In contrast, an architecture of an agent-based wireless local positioning system, mainly for factory level applications, is proposed in this paper. With the aid of agent-based capability, intelligent property can be added on top of the standard positioning system.

Since the deployment of the proposed system is still in its development stage, an account of actual implementation cannot be provided in this paper. In this connection, future works mainly rest on the hardware and software development of the system, with the help of ZigBee specification as discussed above. In addition, more details of the agent-based communication and coordination protocol can be revealed together with the discussion on the implementation of the system, which is another future research direction. Finally, with the help of the network capability of the proposed system, the accuracy of the measuring technique could be improved, which is the second piece of future research work.

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