2015 IEEE Symposium Series on Computational Intelligence

An Agent-based Framework for Indoor Navigation in Blended Shopping

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Abstract—**In this paper we propose an advanced computational intelligence solution for an an Agent-based framework for implementing blended shopping scenarios. The proposed solution meets needs recently arose in Ubiquitous Computing and Pervasive Computing as well. The work focuses on the definition of an Indoor Navigation System that guides shoppers in a shopping mall, towards the shops providing the most suitable offerings for them, in a given time window. Such system is based on a distributed algorithm that runs on a network of intelligent cells sensing both shoppers and offerings by means of the sensor devices deployed in the mall.**

I. INTRODUCTION

Typically, outdoor navigation systems exploit GPS signals that cannot be adopted for the *Indoor Navigation Systems (INSs)* given that such signals cannot be received indoors. Thus, indoor navigation systems must necessarily use alternative techniques for localizing the user: dead-reckoning, direct-sensing, triangulation, and pattern-recognition [1]. In particular, *direct sensing* provides localization methods that determine the location of the user through the sensing of identifiers or tags, which have been installed in the environment. Sensing one tag is sufficient for determining the location of the user and tag reader can be easily embedded in hand held devices or in a shoe or a cane [1]. Moreover, indoor navigation can enable pervasive computing applications in retail store environments. For example, using indoor navigation assistance, retail stores can guide consumers to their desired products or track movement patterns of users to fine-tune product placement [2]. According to the above assertion, we propose an agent-based framework for the indoor navigation particularly suitable for implementing blended shopping scenarios. Blended Shopping is defined by the authors of [3] as the execution of the transaction phases (information, mediation, negotiation, contracting, fulfillment and after-sales) involving both, real sales and presentation mechanisms as well as network based sales functionality. The proposed framework adopts the direct sensing technique for localizing shoppers. The idea is to map the structure of the shopping mall within a mesh and associate intelligent cells (equipped with sensors, processors and actuators) to shops. In this way each cell can sense the presence of shoppers, knows which shops are near and can interact with shoppers to suggests them the next step on the path toward their objective. In order to calculate paths and suggestions we propose a specific distributed algorithm for indoor navigation that lays on such framework and a Mobile App enabling shoppers to interact with the environment (and vice-versa). The system provides advantages for both merchants and shoppers. The advantage for the shopper is clear, they can reach an offering for a product they need and save the costs of their purchases. Moreover, shoppers are guided to their objective by means of context-aware recommendations, thus they can save time within the mall. Furthermore, the system provides a mechanism for direct marketing that enables merchants to reach, with their offerings, people who is really interested in purchasing those kind of products. In order to exploit this mechanism, merchants are encouraged to continuously proposing competitive offerings. Virtuously, this aspect generates lower costs and cost saving for the shoppers.

The paper is structured as follows. Section II provides motivations for the choices conducting to the definition of both framework, algorithm and App. Section III provides details on the definition of the shopping mall as a Smart Environment and its modeling by using the agent-based paradigm. Moreover, the distributed algorithm is presented in Section IV. Section V provides design and implementation details. In Section V-D the user interface of the indoor navigation system is described and, lastly, Section VI provides final remarks.

II. A MOTIVATING SCENARIO

Nowadays it is usual to see shopping malls or big stores proposing weekly or daily offerings (for limited stocks of specific products). By using mechanisms like, for instance, magazines distributed at the entrance of the shop or Web sites. There are two main drawbacks with these traditional tools. In fact, the information shared they provide is not contextualized and cannot be regulated by some adaptation processes. For example, if the stock for a specific product, that is associated to an offering, is finished then it is not possible to suddenly and agilely replace this offering with another one. Unfortunately, the above described capability is desirable because it can enable more flexible marketing strategies that can be adjusted on-the-fly, also by considering the current request (how many shoppers are interested in some kind of product?). In order to provide this capability it can be possible to reason on two facts. The first one is that smart-phones (and other smart

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The work of Mimmo Parente has been partially supported by the project Smart Tunnel (PON04a2_G) of the Italian Ministries MIUR and MISE.

978-1-4799-7560-0/15 $31.00 © 2015 IEEE
DOI 10.1109/SSCI.2015.263

devices) are widespread, so it is reasonable to think that shoppers can receive information about the current offerings while they are in the mall. The second one is that it is possible to empower closed physical environments by using low-cost sensors/actuators exploited (in the context of Wireless Sensor Networks) to sense *presence*, detect *location* and know *desires* (in the form of wishlists) of the shoppers and *suggest* them how to move in the shopping mall to reach and gather offerings to be exploited during the purchase. Both facts contribute to realize an *indoor navigation system* whose objective is to guide shoppers toward the current best offerings related to the products they really need (indicated on their wishlists). We assume that offerings as well as products are localized in the shops which provide them. So, shoppers have to reach these shops to gather offerings and perform the product purchase. The physical environments we are considering are those buildings in which there are numerous shops owned and managed by different merchants.

This scenario provides some clear benefits for shoppers. In fact, they are guided to reach offerings and products they really need and can obtain lower costs for the items they would buy. On the other side, merchants can have the tool to achieve single shoppers and propose only the offerings they are interested in. In case that more merchants provide different offerings for similar products, highest priority is given to the lowest-cost offering.In this way the merchants proposing best offerings are rewarded because they are visible to the shoppers earlier than other merchants.

Although there exist several approaches to realize this kind of *indoor navigation system* we propose an agent-based model implementing the distributed intelligence of the smart environment, that can be embedded in the behaviors of the single cooperating agents. Such agents can map different aspects of the scenario: both shoppers and shops. In this way it is possible to: i) scale to smaller or bigger environments by removing or adding merchant agents representing shops and ii) consider a variable number of inhabitants (of the environment), i.e., shoppers, by adding or removing shopper agents. Moreover, it is possible to adjust the marketing strategies, considering a greater or lesser number of offerings (or modifying the offering contents) by adding or removing offerings that are provided, independently, by each shop but they are made available by a centralized intelligence.

Furthermore, the agent-based model provides us with further desirable characteristics: i) adaptivity, i.e., the distributed algorithm can react on-line (no need to restart the algorithm) to a change of context as, for instance, out of stocks for specific products or shoppers which do not follow precisely the suggested routes, and ii) fault tolerance, i.e., the distributed algorithm adapts (no need to shutdown, reconfigure and restart) to the changes of the environment structure like, for instance, when a new shop is added to the mall or when a there is a failure of the associated hardware (e.g., sensors or actuators).

III. MODELING THE SMART ENVIRONMENT BY MEANS OF THE AGENT-BASED PARADIGM

The Smart Environment in which we execute the algorithm for commerce-based indoor navigation can be defined as a physical environment, i.e., a shopping mall, that is divided in zones and equipped with a wireless network of low-cost devices. A zone can be a shop, a rest area, a corridor (or a part of it), etc. On the top of such layers, a dynamic set of cooperating software agents is employed in order to model structure and behavior of the Smart Environment. The agent-based model of the Smart Environment is proposed in this section. Moreover, the distributed algorithm for commerce-based indoor navigation that runs by means of the cooperation of such agents is described in section IV. Lastly, some design and implementation issues are reported in section V, where is also presented the front-end of the Mobile App by which shoppers receive indications by the environment and communicate their presence.

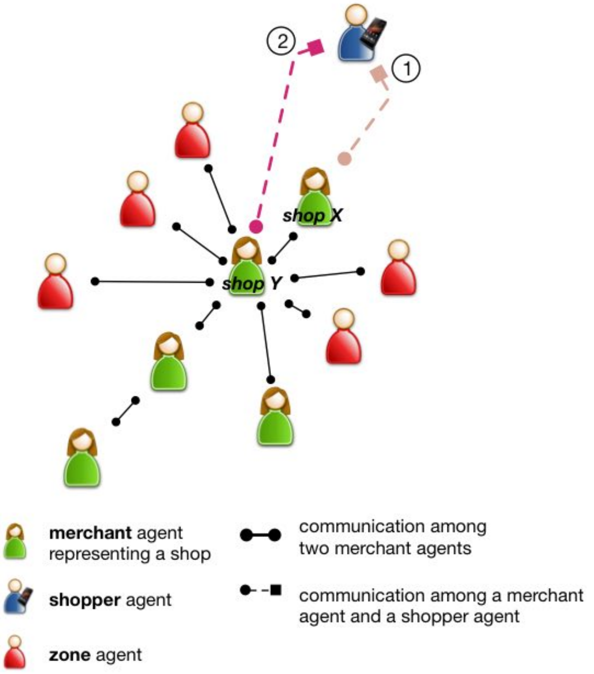

Fig. 1. Agent-based view of the Smart Environment and its inhabitants

Fig. 1 shows a simple example of the agent-based view of the Smart Environment and its inhabitants. Each zone is associated to a *zone agent* able to ”sense” the presence of *shopper agents*, each of these is associated to a shopper that is present in the shopping mall (in that zone), to ”communicate” with them and to ”send/receive” messages to/from its neighbors (other *zone agents*). *Zone agents* can be specialized into several types of agents that provide some specific behavior (in addition to that inherited by the *zone agent* behavior). In particular, there is a *merchant agent* for each zone that is a shop. As we have introduced before, *zone agents* are connected together. The *zone agents* directly connected are called neighbors. Moreover, another type of agents, namely *offering dispatcher agent* (that for simplicity is not reported in Fig.1), is needed to access the *Central Commerce Service* (described in details in section V-C) and communicate to *merchant agents* which are the available offerings for the shops they are associated to. The cooperation among agents allows to implement adaptive and blended commerce as well as innovative marketing strategies. The result of such cooperation is a distributed embedded ”intelligence” we will discuss in section IV. In order to make clear the association between the agent-based model and the physical environment (shopping mall) it is important to note that when a shopper leaves the shop X (circled 1 in the Fig.1) and enter in a different shop Y (circled 2 in the Fig.1), her corresponding *shopper agent* terminates to dialogue with the *merchant agent* X and starts to communicate with the *merchant agent* Y. The adoption of the agent-based paradigm brings a set of advantages as claimed by the authors of [4]:

- to effectively partition the problem space of the complex system;
- to clearly and easily model key abstractions of the complex system;
- to appropriately deal with the dependencies and interactions that exist in complex systems.

Lastly, the agent-based paradigm comes with several ACLs (Agent Communication Languages), like FIPA, which can be adopted [5].

IV. THE DISTRIBUTED ALGORITHM IMPLEMENTING THE EMBEDDED INTELLIGENCE

In this section we provide a formalization of the setting described in the previous section, then we define the *shopping* problem along with a distributed algorithm for its solution. Such algorithm has been called previously as ”embedded intelligence” and is executed by means of the cooperation among a dynamic set of agents.

The Smart Environment (section III), in which the scenario described in section III runs, is naturally mapped with a planar graph where the shop rooms are represented by the nodes and the corridors joining them are the edges (w.l.o.g. if two edges intersect we can add a dummy shop at the intersection point and if a corridor or a rest area is equipped with sensors can be represented as a vertex). It is well-known that any planar graph can be embedded in a 2-dimensional Euclidean space $\mathbb{R}^2$ (see e.g. [6]). As a proof of concept we assume that our scenario is hence a mesh of cells, where each cell is an agent with a finite amount of resources. The agent-based modeling has been described in section III. In particular, cells represents zones of the Smart Environment and, consequently, agents associated with zones. In order to give a formal representation of the model it is natural to adopt Cellular Automata. A cellular automaton (CA) consists of a regular *network* of *extremely simple computers*, (called *cells*) which are essentially Finite State Machines (FSMs). They have been studied since early $'$60s and are still investigated mainly because they combine a mathematical simplicity and elegance with an high level of computational efficiency and efficacy that makes them very suitable to implement real case scenarios [7], [8], [9], [10], [11]. Time is discrete and there is a global clock for all the cells and at each time step each cell is in one of a finite number of *states*. A *neighborhood* relation is defined, indicating the *neighbors* of each cell. All the cells have the same number N of neighbors, except a fixed number of *boundary cells* which have less neighbors (throughout our paper $N = 8$), usually called the *Moore* neighborhood. A cell is linked to each of its neighbors through *communication channels*, and can send and receive, at each global time step, its state. At each time step, every cell updates its state in accordance to a *state-transition function* δ that takes as input the state of the cell itself along with the states of the cells in its neighborhood. Shoppers also are modeled as agents with a finite resources.

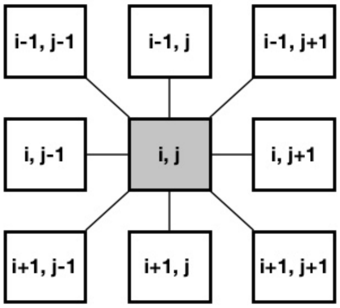

Fig. 2. Neighbors of cell (i, j)

We assume that shoppers do not know the shopping environment and entering this latter their list, saved on a smart device, is gained by the smart environment (clearly with their consensus). At this point the smart environment will guide the customer through the shops to buy the items in the list.

Actually shoppers can be reached, in every zones they are, by means of context-aware information only if they need them. For more deep motivations of the use of CA we refer to the motivation exposed in [12] where the computational model has been enhanced to accomplish robotic mobile scenarios and been defined as Cellular ANTomata. In order to be more specific, in section V we will provide a plausible technological setting, supporting the class of scenarios we will deal with in this paper.

We define now the problem of guiding shoppers to find suitable offerings (best cost offerings for wished products). We call this problem, as well as the associate algorithm, the Offering Finding. The problem resembles that in [12] called the Food Finding problem where the authors propose as computational model the Cellular ANTomata which are classical Cellular Automata with the feature that each cell is equipped “with sensor for ants, obstacles and goals and with a unidirectional communication channel that a resident ant will respond to”. Let a rectangular CA of size $m \times n$ be given, on which r cells contain a single ant and s cells contain a single object, called “food”, with $r, s \leq m \cdot n$.

The *Food Finding* problem consists in designing an algorithm such that if $r \leq s$, then each ant eats a food item and if $s < r$ then every food item is eaten by an ant. Different kinds of food are allowed. The running time of the Food Finding algorithm, proposed in [13], is $O(r \cdot \max{(m, n)})$ steps. This algorithm can be mapped in our Offering Finding Problem as follows. The *shoppers* represent ants and the *products offerings* the food items. We assume that the products offerings are known by a coordinating central unit (see section V-C) which solves conflicts with the shop owners and expose into the *merchant agents* the best offering for each product. The initial condition is that r ant-robots and s food items are distributed across the cells of the mesh. Thus, the algorithm can be now used to guide, step-by-step, shoppers to the most suitable offerings, i.e., offerings for wished products at the lowest cost in the mall.

Let us remark that our approach, being distributed guarantees several advantages with respect to a centralized approach: adaptivity, fault tolerance, time efficiency and reduced costs and last, but not least, scalability.

The algorithm, step-by-step, guides the shoppers to pick up the desired offerings. During the algorithm execution it is possible that the products related to a specific offering are exhausted. In this case, the coordinator will replace the above mentioned offering with a new offering, possibly provided by a different shop, and will enable such shop to broadcast the offering. More in detail, the *shopper agents* await messages from cells possessing the offerings. It begins a new synchronization as soon as the preceding one terminates (each such synchronization takes $(m+n-1)$ time steps, which is also the optimum time to synchronize all the cells of such a network. When the stop criterion is reached by a synchronization, that is when there are no longer shoppers wishing products or when there are no longer offerings, cell $(1,1)$ terminates the algorithm by broadcasting a `TERMINATE` message.

Cell $(1,1)$ broadcasts a message `INITIATE` through an FSSP-type synchronization. At the end of this latter phase, cell $(1,1)$ knows that every shopper- and offering-possessing cell has initiated to participate to the algorithm. This participation proceeds as follows. Every cell possessing offerings (and having not shoppers needing such offerings) broadcasts an `I-HAVE-OFFERING` message, indicating the direction to reach it and also the type of products related to the offering. A cell receiving such a message, relays it in the opposite plane and messages coming from the same direction for the same type of products are merged in one single message. The relaying follows the schemes in Fig. 3, where the message to be relayed goes into the cell (i,j).

The direction of the message indicates the next step that a shopper (interested in that offering) has to undertake in order to reach the shop providing that offering. Thus, shoppers are advised one step at a time. Cells, possessing shoppers who are interested in the offering announced in the received message, send these customers in the direction specified by the message (give him/her a suggestion concerning how to move in the environment). A cell which contains an offering that is picked up by a customer continues to relay incoming messages but stops broadcasting `I-HAVE-OFFERING` messages. Shoppers who reach the shop with a wished product can pick up the offering by means of their smart devices (for instance by means of Bluetooth). A message announcing a particular offering (for a specific product type) continues to be broadcasted throughout the mesh until a customer reaches and picks it up.

The correctness of the algorithm derives from the proof of the *Food Finding* algorithm provided by Rosenberg in [13], [12]. Without loss of generality we assume that: (i) we have r customers interested in the same product type for which we have s available offerings, (ii) each of these customers is interested in only one item related to the above mentioned product type, and (iii) the customers have only one product in their shopping lists. If $r \geq s$ then every customer will eventually follow a message that ends in the cell containing the offering. Shoppers are considered inactive (with respect to the algorithm) if they physically leave or if their shopping lists are empty or do not match with at least one active offering. Otherwise, they are considered active customers. If $s < r$ then some customer will eventually reach every offerings. Lastly, as well as the *Food Finding* algorithm, the process terminates $O(r \cdot \max(m,n))$ steps after either there are not active customer or there are not active offerings.

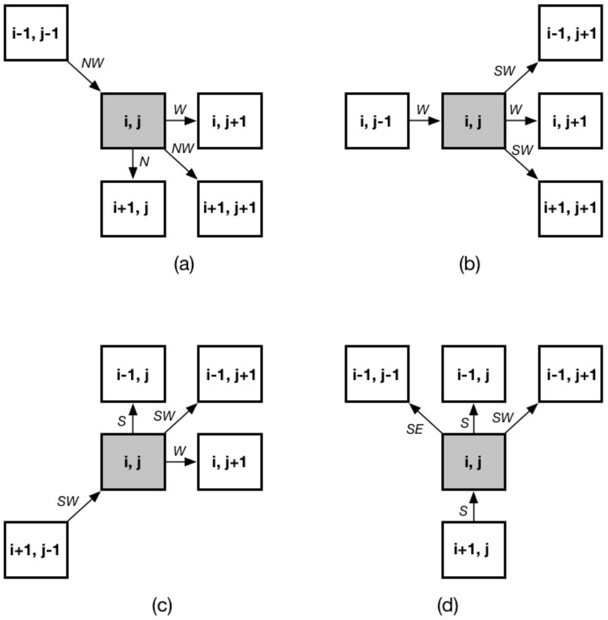

Fig. 3. Scheme for relaying messages at node (i,j)

V. DESIGN AND IMPLEMENTATION ISSUES

In this section we will describe some relevant issues, along with the adopted solutions to solve them, related to the design and implementation of the proposed approach. First of all, we will provide a description of the equipment by which the physical environment is empowered. Secondly, an architectural sketch, showing the information flow related to the indoor navigation system for the offering finding scenario, is described. Thirdly, we will consider in more details the aspects related to the management of offerings and products. Lastly, the user interface of the app provided to the shoppers will be briefly described.

A. Implementing the distributed algorithm

In order to implement the distributed algorithm described in section IV we need to consider an agent middle-ware, a mechanism to synchronize agents associated with cells and a communication language enabling communication and cooperation among agents. In order to be FIPA compliant [5] we adopted JADE (JAVA Agent DEvelopment Framework) [14], an open source platform for peer-to-peer agent based applications. In order to describe the Offering Finding algorithm by using agents, it is possible to adopt the FIPA communication language and provide the main messages exchanged by the employed agents. In particular, we consider the following tasks: broadcast, relay, available-offering, shopper-in-zone, move-to. Take care that the following messages are only examples with sample offerings, sample directions, and so on. Furthermore, the adopted language for representing knowledge is RDF[1] (serialized in N3[2]). In the real implementation, the language will be SPARQL[3] that allows to query, insert, delete, update or construct data by accessing a triple store systems. Lastly, it is also possible to model the knowledge base by using a more formal language such OWL[4]. The choice to adopt the Semantic Web technologies (like RDF, OWL and SPARQL) is due to the chance to foster the integration with the GoodRelations ontology (see section V-C).

1) Broadcast: This message is sent by a *merchant agent* when it has an available offering to communicate to its neighbors. A copy of this message is sent to all neighbors of the sender agent. The message reported below is useful to indicate to the south neighbor that an available offering is toward north.

(**BROADCAST**
:SENDER (aMerchantAgent)
:RECEIVER (theNeighborAtSouth)
:CONTENT
“:anOfferingForProductX :available-at :north”
:LANGUAGE RDF
)

2) Relay: This message is sent by a *zone agent* when it receives a message indicating the availability of an offering. A copy of this message is sent to three neighbors of the sender agent according to the schema reported in Fig. 3.

(**RELAY**
:SENDER (aZoneAgent)
:RECEIVER (theNeighborAtSouth)
:CONTENT
“:anOfferingForProductX :available-at :north”
:LANGUAGE RDF
)

3) Available Offering: This message is sent by an *offering dispatcher agent* when it knows that an offering can be published and communicates this news to the *merchant agent* associated to the the shop providing such offering.

(**AVAILABLE-OFFERING**
:SENDER (anOfferingDispatcherAgent)
:RECEIVER (aMerchantAgent)
:CONTENT
“:anOfferingForProductX :provided-by :aMerchantAgent”
:LANGUAGE RDF
)

4) Shopper in Zone: This message is sent by a *shopper agent* to a *zone agent* when its associated shopper is physically localized in the zone associated to such *zone agent*.

(**SHOPPER-IN-ZONE**
:SENDER (aShopperAgent)
:RECEIVER (aZoneAgent)
:CONTENT
“:aShopperAgent :localized-in :aZoneAgent”
:LANGUAGE RDF
)

5) Move To: This message is sent by a *zone agent* to a *shopper agent* when the cell associated to the zone has received a message for an offering that is needed by the shopper in the zone and comes from west. So the *zone agent* suggests the shopper (through the *shopper agent*) to move one zone to the west.

(**MOVE-TO**
:SENDER (aZoneAgent)
:RECEIVER (aShopperAgent)
:CONTENT
“:anOfferingForProductX :reachable-to :west”
:LANGUAGE RDF
)

B. Equipment of the Physical Environment

From the hardware viewpoint, each zone is equipped with a low-cost mini-computer (e.g., Raspberry Pi) that is connected to a subset of other ones in order to form a network implementing the embedded ”intelligence”. This mini-computer implements the idea of *processor* for a specific zone, receives input from the *sensors* deployed in such zone and provides output to the shoppers and to its neighbors, acting as an *actuator*. Mini-computers have to be deployed into zones (one for each zone) and connected together by means of a wi-fi network. The approach is highly scalable because it is possible to change both the dimensions and the number of zones by considering current goals and budgets. Shoppers interact with the surrounding physical environment by means of their smartphones or wearable devices or the like, in particular, by using wireless network protocols (IEEE 802.11, Bluetooth/Wibree, Zigbee, NFC, etc.). More in details, each zone is equipped with a wireless antenna (receiver/transmitter) by which the *sensors/actuators* perceive the presence (or other properties) of a specific shopper (identified by means of her mobile device) and communicate with her. There is no need to attach sensors to products. Localization can be performed by using Bluetooth sensors [15]. Bluetooth is a low-cost and low-power technology and it is an efficient way to design indoor localization systems. Alternatives to Bluetooth are recognizable in the work [16]. Each shop is also equipped with virtual sensors able to check the availability of specific offerings (for products purchasable in such shop). This capability is implemented by accessing and querying specific software committed to manage products (prices, offerings, availability, etc.). Such model is fully scalable along several and heterogeneous dimensions. In fact, it is possible to expand or reduce the number of shops

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[1] http://www.w3.org/RDF/

[2] http://www.w3.org/TeamSubmission/n3/

[3] http://www.w3.org/TR/rdf-sparql-query/

[4] http://www.w3.org/2001/sw/wiki/OWL

to adapt the system for a wider or smaller environment or, for instance, to increase the number of sensors and actuators to realize more complex scenarios.

C. Management of Products and Offerings

Products and offerings are assumed to be handled by a *Central Commerce Service*. Virtual sensors associated to processors observe data provided by such service and can establish if the zone in which they are deployed represent shops that are currently proposing available offerings. Available offerings can then be gathered by the shoppers in those zone by means of their smart-phones and redeemed during the purchase. In order to provide high levels of interoperability and reasoning capabilities, the GoodRelations Ontology [17] has been introduced in the whole architecture. GoodRelations allows to represent products, offering and shops and their interrelations. Moreover, it is possible also to provide an integration of GoodRelations and the SSN Ontology [18] used to semantically model several aspects of sensor networks. This integration provides semantic relations among shops and sensor devices, i.e., the equipment of the Smart Environment. GoodRelations allows also an ontology reasoning and can be used to execute inferences. This aspect allows us to consider in the wishlist not only specific products, but also product features at different levels of abstraction. For instance, assume you are looking for a blue colored smart device. You consider hence two features: smart-device as the *type* and blue as the *color*. It is possible to construct a `class` by using a *restriction* for classifying suitable offerings for the item satisfying these features. Thus, offerings for *blue smart-phone*, *blue tablets* or *blue smart-watches* will be considered by the ontology reasoning.

Another important aspect of the *Central Commerce Service* is the selection of the available offerings in the mall. If two shops propose offerings for the same product, only the best offering (we assume that with the lowest cost) is published. When products associated with such offering are depleted, then the second best offering is now published.

D. Mobile App for Indoor Navigation System

The *Indoor Navigation System*, to find offerings and products, is composed by the Smart Environment and the algorithm described in the previous sections and by a specific App that must run on the smart-phone of the shoppers. In particular, we will show the effect, for the user/shopper, needing a T-shirt, of the algorithm previously described, when an offering for a `T-shirt` is available. Take a look to the Fig.4 that provide a sample of the execution of the Indoor Navigation System. When the shopper is in the location reported in Fig.4(a) the App suggests her to go ahead in the next shop, positioned at north. The shopper moves to the zone at north and her presence is now sensed by the sensor device deployed in that zone. At this point the shopper receives a new suggestion for moving to the zone at northwest (see Fig.4(b)). Lastly, let us stress that the system is completely adaptive, in the sense that if the shopper does not follow correctly the move suggestions of the system, the environment senses her presence (by using sensor devices deployed in the zone where the shopper is) and starts providing correct direction information to reach the suitable offering. Thus, there is no need to restart the algorithm.

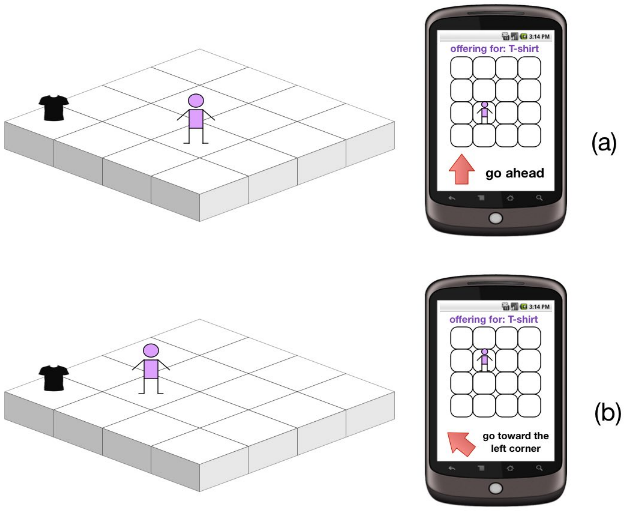

Fig. 4. Sample execution of the Indoor Navigation System

VI. FINAL REMARKS

In this work an agent-based framework for indoor navigation in blended shopping scenarios has been proposed. The adoption of the agent-based paradigms provide a set of advantages related to the modelling task of the complex system represented by the Smart Environment deployed into the shopping mall. The proposed framework allowed the definition of an indoor navigation system that guides shoppers towards the most (in the mall) suitable offerings for products they really need. An important issue to consider is that the shopper is not overwhelmed by the recommendations of his/her smart devices, because such recommendations are filtered by the products really needed by the shopper and are provided only when he/she moves to another mall zone. Moreover, the shopper can look at his/her smart device only when a relevant notification arrives. The smart device App can be configured in such a way to notify (by means of a led or a sound) the arrive of a new recommendation. This happens when the shopper moves to a new zone and he/she is localized by the sensor deployed in that zone. Thus, shoppers are not obliged to continuously look at their smart device. The communication among the environment and the shoppers is enabled by sensors deployed into the environment and by the personal smart devices of the shoppers. The proposed system is based on a distributed algorithm formally defined by using the model of Cellular Automata. The whole system is scalable, flexible and adaptive with respect to changes occurring with respect to the environment. Actually, the authors are planning to deploy, execute and evaluate the proposed system in the context of a set of experimentation activities.

ACKNOWLEDGEMENTS

The authors thank Prof. Vincenzo Loia and Prof. Matteo Gaeta for the helpful discussions and insights.

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