Integrated OPM Wireless for Smart Home

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***Abstract*—Indoor wireless transceivers connect sensors and actuators, which are carried by a mobile agent to the Smart Home Information System (SHIS). In the smart home, the sensors' role is to observe the human activities and home status, while the actuators are to perform assistive and recovery actions for serving the home resident. The SHIS then analyzes the sensors' data and issues the actuation commands for the task of activity recognition and technological assistance provision. By integrating the wireless network management system with the activity recognition system, we could improve three key parameters in the smart home. First, we could apply sensors and actuators efficiently, by spatially positioning the sensors and actuators in the right place at right time. Second, we could decrease the communication delay, by managing the wireless transceivers at the physical and data-link layer. Third, we let SHIS access the Received Signal Strength Indication (RSSI) information, so it considers the spatiotemporal features of the mobile agent observations as additive information for activity recognition. The main ideas of this paper are examined through experimentation with the use of an Opportunistic Mesh (OPM) platform.**

***Index Terms*—WSN, OPM wireless, Smart home, noise, mobile agent, RSSI, object localization**

I. Introduction

The smart home is a home similar environment where the sensors observe the human Activities of Daily Living (ADL) [1]. The Smart Home Information System (SHIS) analyzes the data and through the actuators, it provides technological life assistance services for its resident. One way to observe the activities is to trace the home resident and the ADL objects such as dishes, spoons, and books which are used to accomplish the ADLs. By modeling the movements of the objects, the smart home information system can recognize the activities, predict the future events and discover the anomalies. For instance, if a knife is on the ground, then it is a sort of anomaly [2], whereas it is not supposed to be there.

Recent works on smart home propose wireless communications to substitute the wired connections [3]–[5]. In these works, the Wireless Sensor Network (WSN) transmits sensors' observations from the home status to the SHIS. There are some advantages to employing the WSN in smart home rather than wired home: we may prevent embed of many sensors and actuators all around the home. Also, by use of wireless technology, a typical living home may be smartened easier and faster than wired technology. Moreover, WSN lets mobile agents run in smart home space [6], [7], and it allows implementing the Internet of Things (IoT) concept in home environment [8], [9].

The wireless communications in the smart home and consideration of wireless signal power as a sort of world feature are in the focus of this paper. SHIS analyzes the spatiotemporal features of the observation points for the task of activity recognition and missions the mobile agent to perform actuation in particular locations. We also applied the Received Signal Strength Indication (RSSI) factor to prevent the formation of noise in the smart home [10], so the communication with the mobile agent is smoothed, and trustworthy. Another application of the RSSI factor refers to the navigation of mobile agent in the smart home; it is used to navigate the mobile agent in the smart home environment. This feature is dependent on the distance between the wireless transceivers [11], and we apply it as feedback indicating the actual position of mobile agent on the graphical model [12]. Therefore, we can localize a mobile agent by equipping it with a wireless transceiver in the smart home environment. The mobile agent moves physically in smart home and puts the sensors and actuators in target locations at the required time.

In prior to navigating the mobile agent in the smart home, we require knowing the RSSI measure of each transceiver at any spatial point. In other words, presuming the smart home is equipped with some wireless transceivers, the RSSI power measures per each location are modelled. As a result, the smart home spatial features are defined by the RSSI measures, supposed to be observed at each position.

In this work, fuzzy logic is applied to categorize the smart home observations from RSSI power measures. We use this logic in clustering process, and group the similar data points in common clusters. Then, the centroid of each cluster is estimated, and the world is presented as fuzzy space. In this way, each location in the smart home will have a fuzzy RSSI value, per each transceiver.

We model the smart home areas as fuzzy location. We define each spatial point as a fuzzy position and predict the RSSI power measures supposed to be taken at origin and destination of the mobile agent. This will be used as a criterion to reason if the mobile agent accomplishes the assigned commands successfully in the real world.

The rest of paper is organized as follows: we present the related works in Section II. In Section III, we discuss the spatiotemporal reasoning and the way we apply the mobile agents in the smart home. In Section IV, we briefly present a comparison between a mobile agent based approach with the ambient environment. In Section V, we conclude our work.

II. Related work

Despite the considerable advantages of wireless communications in the smart home, there are some limitations. There are four parameters that cause the noise issue in WSN communications in small living rooms, which are the effect of distance between the wireless nodes, the quantity of the wireless nodes, using busy spectrum and the effect of home regular wireless device [10], [13]–[15]. Besides, the energy consumption should be controlled, and the wireless network should be extensible. The objective in noise prevention is to decrease the communication elapsed time and the spent energy. However, the network structure should accept adherence of the new nodes [13]. Moreover, we will prevent Open System Interconnection (OSI) data-link layer loops, which are caused by transceivers when they retransmit repetitive data packets [17].

Usually, a wireless smart home is a small room, where several wireless sensor nodes should communicate while other wireless services might operate. On the other hand, the WSN communications are limited to physical and data link layers in OSI model. In other words, the WSN packages do not include the information corresponding the OSI network layer and higher levels; WSN nodes do not get IP address, and the routers are not applied in WSN architectures [18]. As a result, in the scope of wireless smart home, the noise may appear in two OSI layers, which are the *physical* and *data-link* layers.

In the *physical layer*, the problem of "busy channels" occurs, while signals interfere and depending on the interfering signal source, the two noise types are identified, which are "spectrum noise" and "stranger network noise". The spectrum noise happens whenever multiple devices start communication in mutual channels. One way to avoid this noise is to search the free spectrum dynamically. The "stranger noise" appears whenever other WSN-irrelevant wireless devices operate in the home environment. In [14], [15], two other noise types are identified, which are the effects of distance between the nodes and the quantity of the nodes in a small environment. The influence of noise may result in the energy consumption and repetition in data transmission. In [13], the noises caused by the stranger devices are introduced, and it is proposed to leave the IEEE 802.11 channels and to use the IEEE 802.15.4 channels as the substitution. The other noise type discussed in [13] refers to the fact that by default the WSN nodes will communicate in similar channels, so the problem of "busy spectrum" arises. To resolve this noise, it is proposed that each wireless sensor node searches the free spectrum dynamically and the nodes communicate in free IEEE 802.15.4 channels.

One distinct objective to employ wireless in smart home is support of the mobile agents. These agents move in smart home environment and may provide customized information about anomalies [20] or anomaly alike situations [12]. In [6], [7], the mobile agents are used as the actuators in smart environment, and particularly in [7] a robot cleans the home environment using wireless technology. In [12], the mobile agent is proposed as a mechanism to provide precise visual observations for object localization in the smart home. In [10], it is discussed how to navigate a mobile agent in smart home, while the four previously mentioned noises are prevented, and in the current work we will integrate the wireless RSSI information to other smart home sensory observations. Therefore, the spatial point on which the mobile agent observes the human activities and home status will be presumable as a parameter to do activity recognition by SHIS. The result provides a criterion to survey how a wireless smart home saves observation hardware for recognition of similar activities.

III. Spatiotemporal reasoning to navigate the mobile agent

The mobile agent is usually equipped with a set of sensors to perform customized observations and also with a set of actuators to accomplish the desired operations. As a result, there are some services that mobile agent is supposed to do in the smart home: It may trace the smart home resident, and watch her/him permanently and it provides the detailed information about the scenes. For instance, in [12] we proposed the job of object localization in smart home for a mobile agent. To do these jobs the mobile agent requires being placed in the right place at right time. Therefore, spatiotemporal features of the home and activities are analyzed, and the mobile agent performs a close observation or provides the demanded actuation; for example cleaning the room [7] at the target position.

The entire scene of smart home is viewed through a unique visual sensor, and geographical position of the mobile agent is mapped on the visual representation. A multi-layer topology for wireless smart home is proposed [10], which prevents formation of physical and data-link layers' noise in smart home. This model lets a minimal subset of transceivers make a link to the SHIS, while the majority of the transceivers are deactivated, when they are not in route between mobile agent and the SHIS, as shown in Fig. 1. In Fig. 1, a noise-free data-link layer path for wireless communication between the mobile agent and the smart home computer is shown. In this section, we will propose a fuzzy representation about the spatial specifications of a multi-layer topology.

Presuming there are n wireless transceivers, then a particular device called Opportunistic Mesh (OPM15) [11], [16], [19] which can access the power of the received signals from each of the nodes in wireless mesh is used. We refer to RSSI power of the signal sent from device i and received at mobile agent receiver, at the position (x, y) by the symbol $RSSI_{i,x,y}$, in which $1 \leq i \leq n$, and x, y are the coordinates. This symbol identifies the dataset of RSSI values in the wireless mesh. In order to make a dataset, a mobile agent, shown in Fig. 2, moves around the smart home area and provides training data about the RSSI values in different corners and areas of the home.

In the next step, the observations dataset is fuzzified. In other words, a fuzzy clustering algorithm builds fuzzy classes

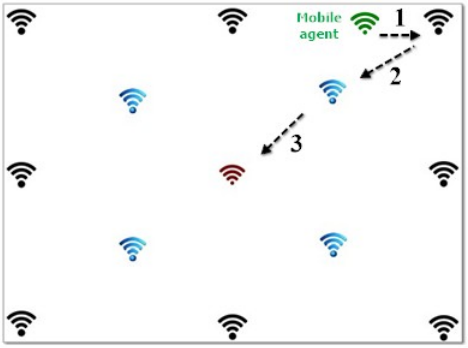

Fig. 1: Data-link layer path between mobile agent and the SHIS in a 3-layer topology. At the topology centre, there is SHIS transceiver (Layer 1) shown by red colour. The black transmitters constitute the exterior layer (Layer 3), which are at the farthest layer from the SHIS receiver. The blue transceivers form the intermediate layer of the smart home (Layer 2).

[12] and represents each class by a centroid:

$$c_{IR} = Fuzzify(RSSI_{i,x,y}, IR) \tag{1}$$

In (1), c represents the centroids matrix and IR is the Influence Range factor, which determines how much the cluster members are alike [2]. By selection of different values of IR, $0 \leq IR \leq 1$, a set of centroids at each influence range will be formed:

$$C = \{c_{IR}, 0 \leq IR \leq 1\} \tag{2}$$

Each member of the set C represents a relative and approximate value of RSSI at influence range of IR between each couple of wireless nodes. As a result, with SHIS, a spatial position is a set of RSSI values, between robot and other transceivers at the visual position (x, y) at influence ranges $0 \leq IR \leq 1$.
When the mobile agent moves to the assigned destination, which is in types of $RSSI_{i,x,y}$, then the absolute difference value between the current and destination positions starts increasing. This will let SHIS to determine if the mobile agent is in right direction towards the destination.

The algorithm proposed in Fig. 3, represents an application corresponding the integration of OPM wireless with smart

Fig. 2: Smart home mobile agent.

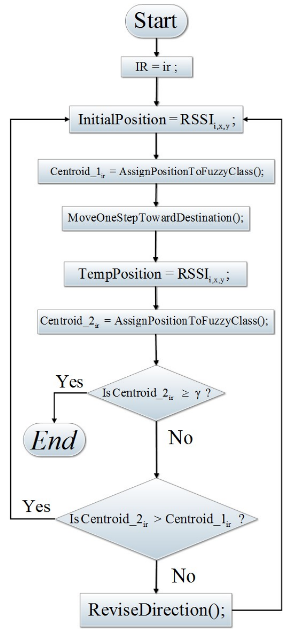

Fig. 3: RSSI feedback algorithm.

home observation/ actuation system. The variable γ represents the desired maximum distance between the mobile agent and the destination.

Primary reason to integrate noise-prevented OPM wireless with smart home information system is to include observation point in activity recognition process [2]. Considering the sensors carried on mobile agent observe the human activities, then the position of mobile agent at the influence range of ir is the additive information to those sensory observations. For instance, if $S_1..S_m$ are the observing sensors then the $\mathrm{RSSI_{i,x,y}}$ is the $(m+1)^{\mathrm{th}}$ variable for analyzing the human activities [2].

IV. Comparison of Ambient Environment with OPM Integrated Approach

In this section, we present a comparison between a mobile agent based approach with the ambient environment one. We presume the proposed approach produces fuzzy centroids regarding the RSSI values. This will be caused by selection of a range of IR values: $0 \leq IR \leq 1$. We consider also that per high IR values, the less imprecise information is produced, and by selection of smaller IR values, more precise information regarding the location of the mobile agent is produced.

We simulate the number of required sensors for recognition of this action in different precision levels. For instance, if human traverses by speed of 1 m/s directly the home width, which is 20 meters, then precise recognition of this action presumably requires six infrared sensors, as shown in Fig. 4.

Six infrared sensors are used for precise action recognition. The mobile agent is designed to recognize this event precisely. The agent performs the close observations at destination points. It takes four seconds to accomplish each command [10]. By setting $IR = 0.18$, the mobile agent moves toward

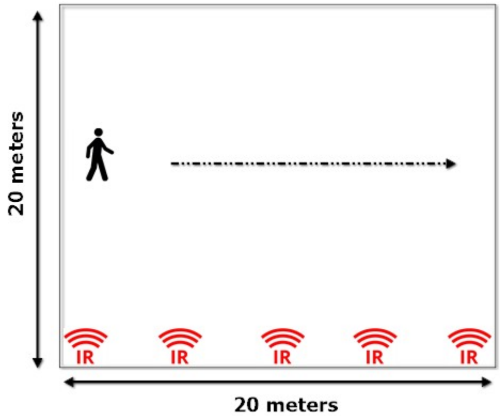

Fig. 4: Precise recognition of walking action with 6 infrared sensors.

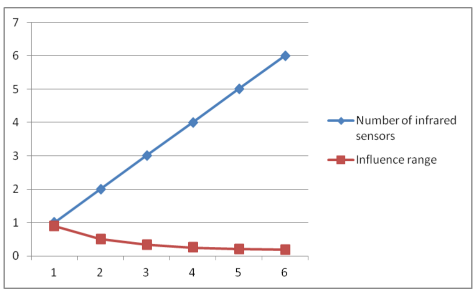

Fig. 5: The relationship between quantity of binary infrared sensors and influence range for recognition of "walking action".

the human, and finds her / him on visual sensor at totally 4 points.

As shown in Fig. 5, for different degrees of recognition for "walking action", we will require how many binary infrared sensors to be embedded. With OPM15 device, we require four seconds for execution of each command by mobile agent, so we cannot set the mobile agent to provide information more precise than $IR = 0.18$.

V. Conclusion

In this paper, we presented an integrated OPM wireless system for smart home. Four types of noise that may form in the smart home environment and may affect the quality of wireless communications between the mobile agent and smart home information system were presented. We proposed an approach that while presenting these noise types, produces spatial specifications of the observation points. This is additive information useful for activity recognition. We also present how the mobile agent application may substituted how many binary infrared sensors needed for recognition of "walking action".

References

[1] L. Chen, J. Hoey, C.D. Nugent, D.J. Cook, Y. Zhiwen, "Sensor-Based Activity Recognition," in *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol.42, no.6, pp.790-808, 2012.

[2] F. Amirjavid, A. Bouzouane, B. Bouchard, "Data driven modeling of the simultaneous activities in ambient environments," in *Journal of Ambient Intelligence and Humanized Computing, Springer-Verlag, Berlin Heidelberg*, vol.5, no.5, pp.717-740, 2013.

[3] M. Li and H. J. Lin, "Design and Implementation of Smart Home Control Systems Based on Wireless Sensor Networks and Power Line Communications," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 7, pp. 4430-4442, 2015.

[4] M. A. Khan, S. Leng, X. Huang, J. Yin and B. Fan, "Backhaul Aggregation for Smart Homes in Heterogeneous Wireless Networks," in *Proceedings of the IEEE International Conf. on Computer and Information Technology; Ubiquitous Computing and Communications*, Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing (CIT/IUCC/DASC/PICOM), Liverpool, 2015, pp. 2206-2211.

[5] M. Y. Fathany and T. Adiono, "Wireless protocol design for smart home on mesh wireless sensor network," in *Proceedings of the 2015 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, Nusa Dua, 2015, pp. 462-467.

[6] D. Schwarz, M. Schwarz, J. Stückler and S. Behnke, "Cosero, Find My Keys! Object Localization and Retrieval Using Bluetooth Low Energy Tags", in *RoboCup 2014: Robot World Cup XVIII, Vol. 8992 of the series Lecture Notes in Computer Science Lecture Notes in Computer Science*, 1st ed., Springer International Publishing, 2015, pp.195-206.

[7] R. Borja, J. de la Pinta, A. Álvarez and J. Maestre, "Integration of service robots in the smart home by means of UPnP: A surveillance robot case study," in *Robotics and Autonomous Systems*, vol.61, no.2, pp.153-160, 2013.

[8] A. Alaiad and L. Zhou, "Patients' Behavioral Intentions toward Using WSN Based Smart Home Healthcare Systems: An Empirical Investigation," in *Proceedings of the System Sciences (HICSS), 2015 48th Hawaii International Conference on*, Kauai, HI, 2015, pp. 824-833.

[9] W. Huiyong, W. Jingyang and H. Min, "Building a Smart Home System with WSN and Service Robot," in *Proceedings of the Measuring Technology and Mechatronics Automation (ICMTMA), 2013 Fifth International Conference on*, Hong Kong, 2013, pp. 353-356.

[10] F. Amirjavid, P. Spachos, L. Song, K.N. Plataniotis, "Dynamic Data Link Model for Wireless Noise Prevention in Smart Home," " in *Proceedings of the 2016 IEEE Global Communications Conference (GLOBECOM)*, 2016.

[11] P. Spachos and D. Hantzinakos, "Scalable Dynamic Routing Protocol for Cognitive Radio Sensor Networks," in *Sensors Journal, IEEE*, vol.14, no.7, pp.2257-2266, 2014.

[12] F. Amirjavid, P. Spachos, K.N. Plataniotis, "3-D Object Localization in Smart Homes," in *Systems Journal, IEEE*, status: under review.

[13] P. Spachos, F. Bui, L. Song, Y. Lostanlen, D.Hatzinakos "Energy Efficient Routing Protocol Design and Implementation for Self-Powered Wireless Sensor Networks", in *IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, 2011, pp. 1140-1144.

[14] M. Perillo, Z. Ignjatovic and W. Heinzelman, "An energy conservation method for wireless sensor networks employing a blue noise spatial sampling technique," in *Information Processing in Sensor Networks, 2004. IPSN 2004. Third International Symposium on*, 2004, pp. 116-123.

[15] A. Keshavarz-Mohammadiyan and H. Khaloozadeh, "PSO-PF target tracking in range-based Wireless Sensor Networks with distance-dependent measurement noise," in *2015 23rd Iranian Conference on Electrical Engineering*, Tehran, 2015, pp. 911-915.

[16] P. Spachos, L. Song, D. Hatzinakos, "Prototypes of opportunistic Wireless Sensor Networks supporting indoor air quality monitoring," in *IEEE Consumer Communications and Networking Conference (CCNC)*, 2013, pp. 851-852.

[17] J. Geier, "Wireless networks first-step". Indianapolis, *Cisco Press*, 2005.

[18] J. Hill, "System Architecture for Wireless Sensor Networks", PhD, University of California, Berkeley, 2003.

[19] P. Spachos, D. Hatzinakos, "Real-Time Indoor Carbon Dioxide Monitoring Through Cognitive Wireless Sensor Networks," in *Sensors Journal, IEEE*, vol.16, no.2, pp.506-514, 2016.

[20] M. Usman, V. Muthukkumarasamy, X. W. Wu and S. Khanum, "Wireless Smart Home Sensor Networks: Mobile Agent Based Anomaly Detection," in *Proceedings of the Ubiquitous Intelligence & Computing and 9th International Conference on Autonomic & Trusted Computing (UIC/ATC)*, 2012 9th International Conference on, Fukuoka, 2012, pp. 322-329.