Wireless Noise Prevention for Mobile Agents in Smart Home

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***Abstract*—In a smart home, the home status, as well as the human activities, can be observed through a number of sensors. A wireless network can transfer the data to an information system and the commands from the information system to the sensors and actuators. In small areas such as smart homes, four types of noise may form in communication system. In this work, we explore how the noise can be resolved by integrating the Wireless Sensor Network (WSN) management with the smart home information system. The result is to smoothen the wireless communication. Additionally, the sensors and actuators are applied efficiently, since the information system places them automatically in the right place at right time. The proposed Opportunistic Mesh (OPM) wireless method avoids signal interference/ collision in small rooms, in order to minimize interference with home regular wireless services, such as WiFi . A model to vector the mobile agent in the smart home is proposed and a mobile agent is used to automatically approach the target positions.**

I. Introduction

The human Activities of Daily Living (ADLs) [1] are an important task for the smart homes. An information system can analyze the data and through the actuators, it can provide 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. A smart home information system can recognize the activities, predict the future events and discover the anomalies, by modeling the movements of the objects.

In smart homes, wireless communications can substitute the wired connections [2], [3], [4]. Wireless Sensor Network (WSN) can transmit sensors' observations from the home status to the smart home information system. There are several advantages in employing the WSN in smart home rather than wired home. For instance, we may prevent embedding too many sensors and actuators all around the home. In addition, by using wireless technology, a typical living home may become a smart home easier and faster than with the use of wired technology. At the same time, WSN let mobile agents running in smart home space [5], [6], and it allows implementing the Internet of Things (IoT) concept in home environment [7], [8].

In this work, four types of noise in the wireless smart home are introduced and analyzed. Two of the noise types are in the physical layer of Open Systems Interconnection (OSI) communication and two of the noise types are in data-link layer of OSI model. To resolve the physical layer noise we improve the transceivers in hardware level [9] . A particular noise problem in the data-link layer refers to the fact that in wireless networks, we cannot segment the network by the use of media. In other words, with wireless mesh, every node is connected to each other and therefore, the "switch" device, which operates at the data-link layer may not be utilized. As a result, although as soon as Opportunistic Mesh (OPM) wireless devices [10], [11] are turned on, they will connect to each other in OSI physical layer, and if we fail to manage the network traffic in very early seconds, the data link layer loops will be formed. For the data-link level noise, we propose a communication algorithm, which manages the sequence of data transmission.

Besides the noise issue, the Received Signal Strength Indicator (RSSI) feature of the WSN signals [12], [13] is used to vector the mobile agent. This feature is dependent on the distance of wireless transceivers, and we apply it as feedback indicating the actual position of mobile agent on the graphical model. The mobile agent moves physically in the smart home and places the sensors and actuators in target locations at required time. The proposed model manages data-link layer noise while it provides the dynamic data-link connections during the transition of the mobile agent.

Finally, we introduce a dynamic data-link model, in order the mobile agent to move and receive the commands smoothly everywhere in the smart home environment. We designed and conducted experiments with a mobile agent to go around and provide close visual observation about the location of the ADL objects. This agent executes predefined commands and presents the noise-prevention efficiency.

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, the target model and algorithms are presented. In Section V, the experimental setup is described. Finally, in Section VI, we conclude this work.

II. Related work

In a smart home, a number WSNs in different small rooms should communicate while other wireless services might operate simultaneously and at the same area. There are many types of noise that can affect the wireless communications in smart homes.

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Two noise types are identified in [14], [15]. The main reason for this type of noise is the 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 [10], [16], 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.

Another noise type discussed in [11] 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 WSN node searches the free spectrum dynamically and the nodes communicate in free IEEE 802.15.4 channels. Fuzzy logic is applied in [17] to categorize smart home observations while in [18], network coding is used to improve the network performance in smart homes.

Although the wireless noise and mobile agents are discussed in separate works, they are not surveyed in an integrated work and the noise issue while using the mobile agents in smart homes are not inspected.

In this work, at first, we will illustrate how the distance causes the noise to appear in WSN smart home. Then, we will present the effect of nodes' quantity in the production of the noise. One distinct objective to employ wireless communications in smart home, is support of the mobile agents. These agents move in smart home environment and may provide customized information about anomalies [19] or anomaly alike situations. In [5], [6], the mobile agents are used as the actuators in smart environment, and particularly in [6] a robot cleans the home environment using wireless technology. In [17], the mobile agent is proposed as a mechanism to provide precise visual observations for object localization in the smart home.

III. Spatiotemporal reasoning to vector the agent

The mobile agent is equipped with a number of sensors to perform customized observations, as well as with a number of actuators to accomplish the desired operations. In this section, the placement of the mobile agent in target position is discussed, followed by the WSN structure in vectoring process.

A. Placing the mobile agent in target position

One distinct application of mobile agents is to provide close observations at the target positions in the smart home for the Object Localization Information System (OLIS). This system demands close images from the particular scenes to localize precisely the objects. In order to place the mobile agent in the target position, discovering the agent's actual position and determining the approach path is necessary. At the same time, OLIS gets feedback to check if the agent is in the correct direction. The power of the wireless signals depends on the distance factor. Analysis of the signal power can provide an estimation of the actual distance between transceivers. In this way, the RSSI feature of the smart home signals is a criterion to check the position of the mobile agent. The other criteria

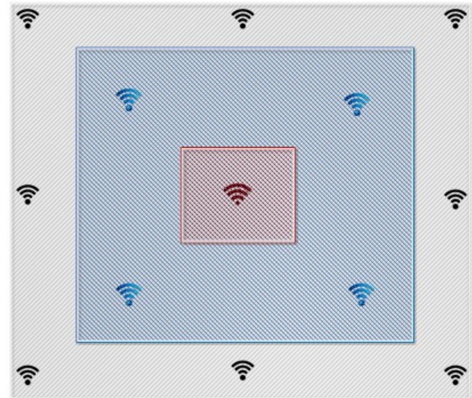

Fig. 1: Wireless zones in smart home. The shaded zones correspond to the wireless layer. For instance, the black shaded zone corresponds to the WSN layer 3 devices.

used to estimate the objects' positions are the angles between objects and the relative distances on the graphical models. This information is taken out from the smart home scenes by the graphical analyzer.

B. WSN structure in vectoring process

When all the wireless transmitters share permanently their data streams, this will cause the "overhead" noise. On the one hand, the WSN is a media to deliver the data stream of the mobile agent, while on the other hand only a subset of the wireless transceivers is supposed to get active in data delivery operation. For this reason, an algorithm was designed, which lets a set of proper devices repeat their received data in the shared wireless media, while the irrelevant transceivers are deactivated from the data delivery process. Selective activation of wireless nodes may lead to decrease the energy consumption too [19].

The other factor which affects the noise issue in WSN is the "distance" [14], [15]. This factor causes, imprecision in the interpretation of received signals at receivers. A solution to this problem could be the coverage of the smart home with a number of transceivers which are placed close to each other.

In this work, to prevent the irrelevant transceivers repeat data streams (or to prevent the loop) in shared wireless media, and to prevent distance noise, multilayer topology for the smart home WSN is proposed. In this way, the OLIS transceiver is at the centre of WSN topology, and the intermediate layers' transceivers at proper distances to repeat data.

A multilayer topology for smart home WSN is shown in Fig. 1. Experimentally, the distance of any blue device to the red one is designed to be smaller than 10 and greater than 5 meters, so that the distance noise is prevented. Similar distance specifications are applied, between each black transceiver the blue transceivers.

The wireless transmitters in the smart home deliver the mobile agent sensor observations to the OLIS. They transmit the OLIS commands to the mobile agent, and they provide vectoring signals for the mobile agent to approach the target position. The other role of wireless nodes is to use their graphical appearance for object localization at graphical analyzer.

As soon as the WSN hardware devices are turned on, the wireless OPM mesh will be formed in OSI physical layer, and they will connect to each other. Although the physical layer noise issue is already resolved in the design of the hardware, the data-link layer noise matters.

IV. Target approach model

In this section, a model which forms dynamically data-link layer paths between OLIS and mobile agent with the multilayer WSN topology is proposed. To approach a target position in the smart home environment, the target position was formalized. The physical path to the mobile agent approaches is the same path, which forms in data link layer for data delivery. The communication layer forms before the mobile agent moves. The mobile agent declares its status (busy or ready to get new command) once per second. When the mobile agent receives a command, it sends OLIS the busy status message while it sends the ready message right after accomplishment of the command.

As the mobile agent moves in the smart home area, the WSN supports the data-link layer connections. The main goal is the prevention of the "overhead" and "distance" noise. The proposed dynamic WSN structure model selects one device per each layer and connects them.

The first concept in the wireless smart home is the "WSN layer", by which the distance and position of each wireless transceiver is identified. Each transceiver supports smooth reception and transmission of signals in particular areas. We refer to them by the term "WSN zones". The zone which is under coverage of the transmitters at layer 1, layer 2 and layer 3, are called zone 1, zone 2 and zone 3, respectively.

Wherever the mobile agent is in the smart home area, it is connected to all other nodes in physical layer. However, in data link layer, it is in point to point communication with only one node. If it is in black zone, then only one device in layer 3, and one device in layer 2 make data link communication path to the OLIS.

The communication path refers to the corresponding transceivers at each layer, which create a path. It is formed automatically by RSSI power measurement. In due time, each black transmitter (layer 3 device) requests data-link connection to the closest layer 2 devices. Figure 2 shows the WSN data-link communication paths.

In Fig. 2, it is shown that each device in higher level will be connected to only one device in lower layer. The lower layer devices will not repeat transmission of the read data in wireless network unless they have an "active node" in their subset and the data is coming from their point to point connected node. "Active node" is connected directly to the mobile agent and the "active path" is the one that has mobile agent connected to any of its elements.

In Fig. 3, it is shown that the data link layer connection between the mobile agent and OLIS is dynamically checked. If a node or its child is connected to the mobile agent, then

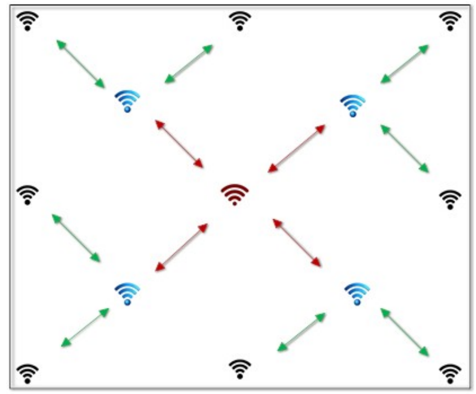

Fig. 2: Wireless data link paths between WSN transmitters

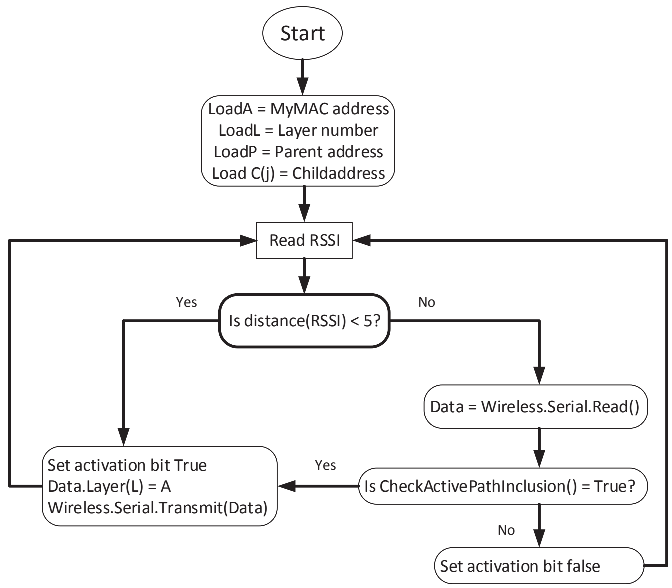

Fig. 3: Wireless data link path algorithm

it becomes active and repeats the incoming data. Algorithm 1 explains the steps during the wireless serial transmit method and Algorithm 2 the steps during the check active path inclusion method. The proposed algorithms prevent forming the loops and overhead while they delivers data to the far distances.

Algorithm 1 Wireless Serial Transmit

```
Wireless.Serial.Transmit(obj Data){
while (True) do
    temp_var = Wireless.Serial.Read();
    if (temp_var == busy) then
        break;
    Wireless.Serial.Write(Data);
}
```

In Fig. 4, the algorithm to vector the mobile agent to the target position is shown. Through reading mobile agent information each time, the MAC addresses at layers 1, 2 and 3 are taken. There is a function which reads the MAC addresses

Algorithm 2 Check Active Path Inclusion

```
bool CheckActivePathInclusion (obj Data){
int x;
for (x=1; x¡L; x++) do
    for (y=1; x¡j; y++) do
        if (Data.Layer(x) == c(y)) then
            return true;
return false;
}
```

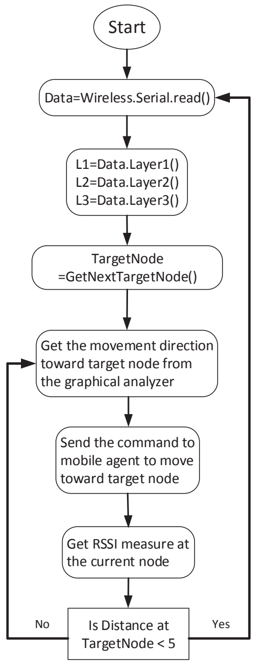

Fig. 4: Vectoring mobile agent to target position algorithm

and reruns the next target node. This procedure, at first, brings the agent to the home centre and then from the central area it vectors the agent to the target destination. The order of traversing nodes are the same data link paths, which the expert defines for the WSN.

V. Experimental setup

OPM15 [9], which operates in ZigBee channels, and forms the wireless mesh at early moments (less than a second) after they are turned on, was used. In the physical layer, the OPM15 devices will find the free spectrum dynamically. The second noise which refers to the effect of stranger devices and networks exists already in regular houses, where the wireless services such as WiFi are often used. They usually apply the IEEE standard protocol 802.11 channels. With OPM 15 devices, WSN avoids operating in the IEEE 802.11 channels and applies the channels corresponding to the IEEE standard protocol $802.15.4$. The other reason to apply this protocol is to spend less energy rather than 802.11. As a result, the smart home WSN works independently from the market-regular wireless devices and is energy efficient.

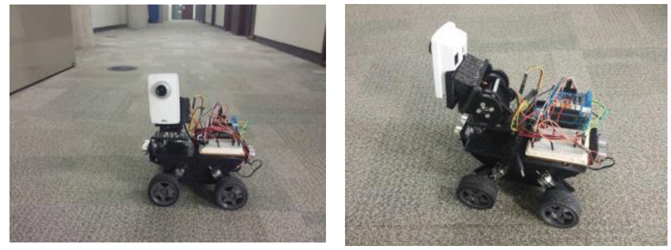

Fig. 5: Smart home mobile agent

The data is transmitted and received in frames at the size of one byte. The default baud rate is 9600, and the parity bit is not applied. Each node is set to transmit the next data byte after waiting one second, while the receiver waits also a second before reception of the next data byte, and the frequency band is 2.4 GHz. We also used a mobile agent, shown in Fig. 5, which gets the commands wirelessly. The mobile agent is also equipped with a visual sensor, which transfers data with IEEE 802.11 standard. This agent is employed to perform the noise analytics experiments and to test the algorithms.

The mobile agent gets the command messages from the transmitters with maximum of 20 meters distance. It speed is $25\ cm/s$. When it gets the command "move forward", then it moves all the wheels for one second with the steady speed and after one second it brakes. The commands and specifications that the mobile agent performs are shown in Table I.

Command	Duration	Description
Move forward	1 second	Moves all four wheels toward forward with the speed of 25 cm/s.
Move backward	1 second	Moves all four wheels toward backward with the speed of 25 cm/s.
Turn right	1 second	Moves two left wheels toward forward and two right wheels toward backward.
Turn left	1 second	Moves two right wheels toward forward and two left wheels toward backward.
Watch right	1 second	Turns the installed camera to the right.
Watch left	1 second	Turns the installed camera to the left.
Watch forward	1 second	Turns the installed camera to the centre.

TABLE I: Mobile agent commands

With a particular configuration, it takes 80 seconds for this agent to traverse the distance of 20 meters and at each second the moving car sends a different byte, which lets us trace the sequence of received data. Experimentally, some bytes are not received expectedly in either content or correct sequence. We refer to this phenomena by the term "distance" noise. Figure 6 shows the successful/ unsuccessful data delivery.

In Fig. 6, the value zero indicates the unsuccessful delivery at the corresponding distance. The effect of distance noise is approximately 26% in this test. The car speed is steady in all the path while the noise appears mostly wherever the distance is greater than 10 meters. In another test, we placed the transmitters at a fixed point, at the distance of 5 meters and sent the data stream, whereas all 80 bytes are transferred properly. Then, we repeated the test by placing the transceivers at the distance of 20 meters, whereas only 65% of the data bytes are delivered correctly (correction algorithms are disabled). The distance noise may be resolved by applying the IEEE $802.15.4$ wireless repeaters wherever the nodes' distances are greater than 10 meters. These devices

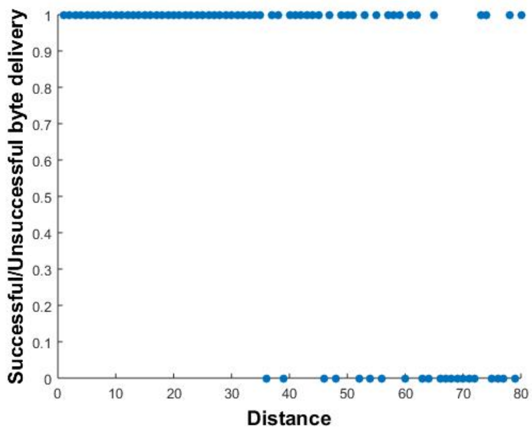

Fig. 6: Distance noise effect in smart home

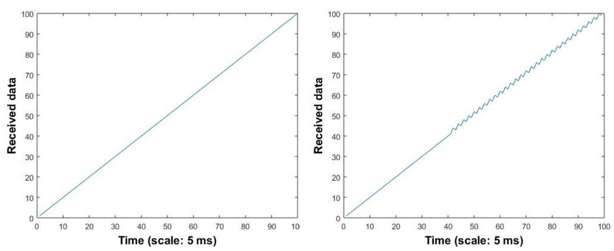

Fig. 7: Overhead Noise effect in smart home

read wireless data and resending it in the wireless network.

The fourth surveyed noise type is referred to by the term “overhead”. This noise is caused whenever multiple wireless devices try to transmit the data simultaneously over the WSN. In the following example, we demonstrate the effect of overhead noise. In this experiment, a transmitter sends the numbers $\{x|x \in N, 0 < x < 101\}$ in a sequenced manner and one digit per each $5\ ms$. Then, we place another transmitter beside the first transmitter and we set the first transmitter to send $\{x = 2k|k \in N, 0 < k < 51\}$ and the second transmitter to send $\{x = 2k + 1|k \in N, 0 \leq k < 50\}$ in an ordered manner and one digit per each $10\ ms$. Figure 7 shows the received data.

In Fig. 7, it is shown that the overhead noise may affect the order in reception of data. In the right side schema it is shown that some bytes are not received in proper order. In order to prevent this problem in wireless smart home, we will apply the algorithms which get feedback to make sure about the correct order of the received data. The ultimate effect of noise is the increment of the communication delay and resending the data. If we do not control the noise effect in the small environment of living rooms, the commands and feedbacks will not be delivered properly and the total data delivery time increases progressively.

A. Experimental procedure

An ADL object (a knife on the ground) is to be localized [20]. There are two wireless transmitters around the object, which are graphically recognizable. The object location is vague if it is on the ground. To decrease uncertainty about the object location, OLIS commissions the mobile agent to go around the object so that two information types will be added to the knowledge data base. The first one is the closer viewed image from the scene and the second one is the new information that the far viewer camera creates. In the current experiment, the process of mobile agent vectoring is surveyed. Also, we will analyze how the data link layer communication algorithms help to decrease the effect of noise in smart home. The distance between wireless transmitters is 7 meters.

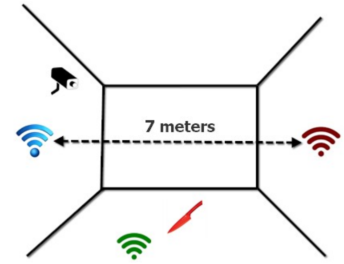

Fig. 8: Experiment scene. Red transceiver is the OLIS’ one, blue transceiver is a layer 2 communicator and the green transceiver is installed on the mobile agent.

In Fig. 8, it is shown that the in scene transceivers are installed on the wall and their distance is 7 meters. The camera watches the transceivers and the ADL object, which are graphically recognizable. In this scene the camera requires assistance of mobile agent to discover if it is either on the ground or on any other object. Non-ADL objects are not graphically recognizable.

In this experiment OLIS at first commissions going around the blue transceiver and then the red transceiver. Then, in graphical environment, OLIS compares the position of the mobile agent with the other wireless communicators.

We performed the test with both noise-prevented and no data-link filter approaches. In both tests, the mobile agent departs from the room centre. At first, it moves toward the OLIS transceiver and then toward the blue one. In Table II, the issued commands are shown. Every command will be executed during one second.

Command No	Command	Execution duration
1	Turn right	1 second
2	Move forward	1 second
3	Turn left	1 second
4	Move forward	1 second
5	Turn left	1 second
6	Move forward	1 second
7	Move forward	1 second

TABLE II: OLIS writing commands

In Fig. 9, it is shown that although the first command is executed in the first four seconds by any of the approaches, the noise-free strategy will remain busy for a long time. The data-link managed approach performed each command in four

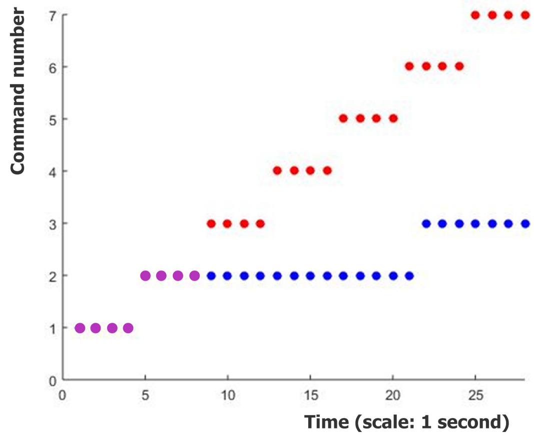

Fig. 9: OLIS writing commands [1-7]. The blue points correspond to non-managed strategy, and the red points correspond to data-link managed strategy.

seconds, and it takes totally 28 seconds to provide additional information for the OLIS. Experimentally, by the unmanaged method we cannot expect accomplishment of more than two or three commands because the "overhead" and "distance" noises will cause that much repetitions, which occupies the network bandwidth.

VI. Conclusion

In this paper, we presented four types of noise that may form in the smart home environment, which may affect the quality of wireless communications between the mobile agent and smart home information system. Two particular noise types are important to the OSI data link layer. To resolve the issue, we proposed to manage the data streams in OSI data-link layer, while a model which communicates with mobile agent everywhere in the house is introduced. This model prevents the data-link layer noise while it is in smooth communication with the mobile agent. The model is tested with a localization scenario, and the 28 first seconds of the mobile agent behaviour in both noise-managed and noise-unmanaged methods are compared. During this experiment, the mobile agent accomplished four more commands out of totally seven commands with noise-managed method rather than the noise-unmanaged plan.

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References

[1] L. Chen, J. Hoey, C. D. Nugent, D. J. Cook, and Z. Yu, "Sensor-based activity recognition," *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, vol. 42, no. 6, pp. 790–808, Nov. 2012.

[2] M. Li and H. J. Lin, "Design and implementation of smart home control systems based on wireless sensor networks and power line communications," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 7, pp. 4430–4442, July 2015.

[3] M. A. Khan, S. Leng, X. Huang, J. Yin, and B. Fan, "Backhaul aggregation for smart homes in heterogeneous wireless networks," in *2015 IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing*, Oct. 2015, pp. 2206–2211.

[4] M. Y. Fathany and T. Adiono, "Wireless protocol design for smart home on mesh wireless sensor network," in *2015 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, Nov. 2015, pp. 462–467.

[5] 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 [papers from the 18th Annual RoboCup International Symposium, João Pessoa, Brazil, July 15*, 2014, pp. 195–206.

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

[7] A. Alaiad and L. Zhou, "Patients' behavioral intentions toward using wsn based smart home healthcare systems: An empirical investigation," in *2015 48th Hawaii International Conference on System Sciences*, Jan. 2015, pp. 824–833.

[8] W. Huiyong, W. Jingyang, and H. Min, "Building a smart home system with wsn and service robot," in *2013 Fifth International Conference on Measuring Technology and Mechatronics Automation*, Jan. 2013, pp. 353–356.

[9] P. Spachos, L. Song, and D. Hatzinakos, "Prototypes of opportunistic wireless sensor networks supporting indoor air quality monitoring," in *Consumer Communications and Networking Conference (CCNC), 2013 IEEE*, Jan 2013, pp. 851–852.

[10] P. Spachos and D. Hantzinakos, "Scalable dynamic routing protocol for cognitive radio sensor networks," *Sensors Journal, IEEE*, vol. 14, no. 7, pp. 2257–2266, July 2014.

[11] P. Spachos and D. Hatzinakos, "Real-time indoor carbon dioxide monitoring through cognitive wireless sensor networks," *IEEE Sensors Journal*, vol. 16, no. 2, pp. 506–514, Jan. 2016.

[12] P. V. Mekikis, E. Kartsakli, A. S. Lalos, A. Antonopoulos, L. Alonso, and C. Verikoukis, "Connectivity of large-scale wsns in fading environments under different routing mechanisms," in *2015 IEEE International Conference on Communications (ICC)*, June 2015, pp. 6553–6558.

[13] P. V. Mekikis, A. Antonopoulos, E. Kartsakli, L. Alonso, and C. Verikoukis, "Connectivity analysis in wireless-powered sensor networks with battery-less devices," in *2016 IEEE Global Communications Conference (GLOBECOM)*, Dec. 2016, pp. 1–6.

[14] M. Perillo, Z. Ignjatovic, and W. Heinzelman, "An energy conservation method for wireless sensor networks employing a blue noise spatial sampling technique," in *Third International Symposium on Information Processing in Sensor Networks, 2004. IPSN 2004*, April 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*, May 2015, pp. 911–915.

[16] P. Spachos, P. Chatzimisios, and D. Hatzinakos, "Energy efficient cognitive unicast routing for wireless sensor networks," in *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, June 2013, pp. 1–5.

[17] F. Amirjavid, P. Spachos, L. Song, and K. N. Plataniotis, "Integrated opm wireless for smart home," in *2016 Digital Media Industry Academic Forum (DMIAF)*, July 2016, pp. 139–142.

[18] F. Amirjavid, P. Spachos, L. Song, and K. N. Plataniotis, "Network coding in internet of things," in *2016 IEEE 21st International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD)*, Oct 2016, pp. 140–145.

[19] M. Usman, V. Muthukkumarasamy, X. W. Wu, and S. Khanum, "Wireless smart home sensor networks: Mobile agent based anomaly detection," in *2012 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing*, Sept. 2012, pp. 322–329.

[20] F. Amirjavid, A. Bouzouane, and B. Bouchard, "Data driven modeling of the simultaneous activities in ambient environments," *Journal of Ambient Intelligence and Humanized Computing*, vol. 5, no. 5, pp. 717–740, 2014.