ABSTRACT

This paper proposes a new design for the smart home using the wireless sensor network and the biometric technologies. The proposed system employs the biometric in the authentication for home entrance which enhances home security as well as easiness of home entering process. The proposed smart home Wireless Biometric Smart Home (WB-SH) design is one of the few designs or it is the only design that addresses the integration between the wireless sensor network and biometric in building smart homes. The structure of the system is described and the incorporated communications are analyzed, also an estimation for the whole system cost is given which is something lacking in a lot of other smart home designs offers. The cost of the whole WB-SH system is determined to be approximately $6000, which is a suitable cost with respect to the costs of existing systems and with respect to its offered services. WB-SH is designed to be capable of incorporating in a building automation system and it can be applied to offices, clinics, and other places. The paper ends with an imagination for the future of the smart home when employs the biometric technology in a larger and more comprehensive form.

Keywords: Actuator, Biometric, Smart Home, Vein Recognition, Wireless Sensor Networks.

1. INTRODUCTION

Home automation, intelligent house, smart home, home environment automation and control, systems integration, home network, home area network, management of home from anywhere, or domotics all refer to one thing which is a system uses different technologies to equip home parts for more intelligent monitoring and remote control and enabling them for influential harmonic interaction among them such that the everyday house works and activities are automated without user intervention or with the remote control of the user in an easier, more convenient, more efficient, safer, and less expensive way.

Smart Home (SH) has been a feature of science fiction writing for many years, but has only become practical since the early 20th Century following the widespread introduction of electricity into the home, and the rapid advancement of information technology [1], [2].

The first "wired homes" were built by American hobbyists during the 1960s, but were limited by the technology of the times. The term "smart house" was first coined by the American Association of House builders in 1984 [3]. With the invention of the microcontroller, the cost of electronic control fell rapidly and during the 1990s home automation rose to prominence [1]. Despite interest in home automation, by the end of the 1990s there was not a widespread uptake - with such systems still considered the domain of hobbyists or the rich [2].

In 1998, Corien van Berlo, Ad’s partner, setup SHs together with her husband. The aim was primarily to further the promotion of home automation, execute demonstration projects and start experiments. These demonstration projects were finished in 2000 and 2001, but the importance of these projects is still enormous [4].

The breakthrough in SHs, which emerged tentatively in 2001, saw the Van Berlos employ staff for SHs for the first time and build the smartest home of the Netherlands. Through cooperation with many participants to whom SHs is very grateful, the significantly renewed demonstration home was opened in Tilburg at the end of 2001 [4].

Home control technology is amongst the handy developments that have been formulated yet still developing today. The latest report on the global home automation and control systems market from Global Industry Analysts (GIA) predicts that the global market for SH will touch US$2.8 billion by the year 2015 [5]. In [6] it was argued that the importance for safety and convenience, technological advancements in home automation, and rising demand from both European and emerging countries are the major factors driving growth in the home automation market.

Electrical devices participating in SH systems have to be integrated with some sort of communication protocols.
These protocols may operate over power line, infrared, radio frequency wireless communication or a combination of power line and wireless technologies, also some systems use additional control wiring or other physical media, e.g. twisted pair cables [7], but wiring is expensive for building SHs, running structured wiring in an existing home may cost $1,000 to $3,000, compared to $600 to $2,000 for new homes, not including the cost of a central controller [8].

Power line communication technologies use the household electrical power wiring as a transmission medium, and this enables SH without installation of additional control wiring, but, because this method transmits coded communications signals over the same wires that are used for AC power in a house, the power wire circuits have only a limited ability to carry higher frequencies. The propagation problem and electrical noise are some of the limiting factors for power line communication, in addition to the loss of flexibility and comprehensiveness as it controls only the appliance that uses AC power [7].

The requirements from a SH system to a radio frequency wireless communication technology are low-cost, low-power, range from 15 to 100 meters, and only low transmission rates are needed. The IEEE has developed a standard to meet these requirements which is the IEEE 802.15.4 [9]. The 802.15.4 standard only specifies the physical layer and media access control layer, for the upper layers there are several different opportunities like ZigBee [10] and 6LoWPAN [11].

Wireless systems are less expensive than wired, on average a wireless system costs between $100 and $150 for each connected device and device controller [12], more flexible, easier in installation and maintenance, and haven’t the limiting factors of power line communication, so they will be the focus of this paper.

The infrared is mainly used for point-to-point control flow. There is no bi-directional information exchange. Even though universal remotes have been around for a long time, their line of sight issues and non-interchangeability prevent them from being considered as a technology for SH [13].

The emerging technology, Wireless Sensor Network (WSN) [14]-[20] which is a wireless network consists of a potentially large set of small and smart sensor nodes equipped with a processing unit, storage capacity, and sensing unit for sensing a physical phenomena such as temperature, pressure, etc., plays an important role in implementing SH systems; in addition to that it doesn’t require infrastructure, offers a low cost solution, and its self-configuration capability simplifies the setup of SH systems. As SH is an application requires not only monitoring but also reacting on the physical world with high precision and prompt reaction, the WSN used in SH systems should be enriched with actuators forming what is known as Wireless Sensor and Actuator Network (WSAN).

This paper proposes a system called Wireless Biometric Smart Home (WB-SH) for SHs implementation using WSAN describing its components and its proposed communication scenario. The WB-SH uses another promised technology can increase the security as well as the customizability of home environment which is the biometric recognition or, simply, biometrics which refers to the automatic recognition of individuals based on their physiological and/or behavioral characteristics. By using biometrics, it is possible to confirm an individual’s identity based on “who he/she is,” rather than by “what he/she possesses” (e.g., an ID card) or “what he/she remembers” (e.g., a password) [21]. So, also this paper refers to and imagines how can be the future SH using the integration between different emerging technologies, on the top of them, are the WSN and biometric.

The rest of this paper is organized as follows. Section 2, describes the services offered by the WB-SH system, Section 3, gives a scenario of the system in an example flat, Section 4, imagines the next generation SH, Finally Section 5, represents the conclusions and future trends.

2. WB-SH SYSTEM SERVICES
The WB-SH system suggested in this paper provides seven services or in other words it is composed of seven subsystems, may be purchased and installed separately or in different combinations, which are the entering system, the burglar detection system, the burglar deception system, monitoring and controlling home components system, monitoring home structure health system, home plants care system, and Internet access system.

2.1 Entering System
Far from the problems of fostering policy dogs and the problems of the ordinary keys and kallons from imitation, loss, breaking of keys in kallons, difficulty in opening to the extent that the door couldn’t be opened, etc., in the WB-SH system, the entering authentication will be through pattern recognition. The home entering will be through a Two-Factor Authentication (TFA, T-FA, or 2FA), but in this system the two authentication factors will be “Something the user is” for easy entering, the user of the system will only put his right thumb finger in a special place on the wall and then open the door by turning its knob with his right hand palm.

This is a very easy way for entering, in the same time, it is very secure. This process is achieved by making the front door closed by electronic knob and bolt. The bolt is controlled by a fingerprint recognition sensor reading transferred
wirelessly to a central control unit (PC or laptop) where resides a Data Base (DB) of legal fingerprints for home owners. The electronic knob also controlled by palm vein recognition (see Figure 1). If the central controller evaluates that the two patterns match the person, it sends an “open command” wirelessly for the electronic bolt then for the electronic knob.

**Figure 1** New palm vein knob

### 2.2 Burglar or Intruder Detection System

Because there are other illegal entering points in the home rather than the legal method for its entry through front doors, for strengthening home security system, it should be assumed that the authenticated system for entering the home has been penetrated in some way. So, in WB-SH, a motion sensor will be attached to each front door to detect its motion, the motion sensor tells the central control unit if it detects that and the central unit decides if the opening of the door is upon an order from it or not. If this is not within its knowledge, it translates this action as an intruding and sends a warning signal to a not loud buzzer and a flash lamp exist in a room dedicated to the building keeper, also the room contains an LCD shows the number(s) of the home(s) has the problem, different sensors can also be used such as a speaker reads the home number. Upon this warning, the keeper takes the suitable action; this facility is used only if this automation system is a part of a building automation system.

Also in the WB-SH proposed scenario, after a specified time, the central unit orders an alarm buzzer in the home itself to ring loudly. The central unit also translates as intruding a subsequent specified number of failed trials to authenticate, but in this case it sends the warning signal only to the keeper sensors. The motion sensors can also be attached to the other illegal entering points such as windows and balconies’ doors. These windows are opened and closed frequently along the whole day time by the home owners; so, the motion sensors start and end work upon a command from a special mobile remote control unit designed to send simple control commands to home apparatuses and programmed with a special code to be designated from any other remote control, the apparatuses tell the central control unit that they begin to work or end to work.

If windows motion detected, it is signaled directly to buzzers in each part of the home and to the remote control LCD display to show the place of the event, and after a specified period if the motion sensors haven’t been stopped by the remote control, the central control unit warns the buzzer at the building keeper room or the loud alarm buzzer in the home; with this arrangement, the time of these motion sensors work is selected, for example, when the home owners are outside, during sleeping periods, when the mother wants to prevent her children from widows opening, etc.

### 2.3 Burglar Deception System

To increase the security and aid in preventing the crime before its occurrence, the WB-SH proposes to deceive the burglar by simulating the home being occupied and its residents are awake while they are out or asleep. For example, the central control unit can be prepared with a time schedule for opening and closing the light in different parts of the home and playing a recorded voice for the residents and other voices suggest that there is a movement in the home.

### 2.4 Monitoring and Controlling Home Components System

The aim of this subsystem is to automate and improve some home activities and to sustain the home inhabitants and apparatuses safety. The WB-SH automates the home lightening, automates the opening and closing of windows, saves electric equipments from malfunctioning, and saves humans from gas leakage and fire.

#### 2.4.1 Light control

The light switches will be opened and closed electronically in addition to the ordinary method. The central unit will command some selected lamps to open for the person who enters the house after he is authenticated, for example, the
two lambs in the entrance hall and the rooms’ corridor. Also, all the lambs will be turned on/off through the home remote control or by the central controller commands if certain specified different situations happened (this option can be used in the burglar deception system).

Generally, the user of the system can choose the lambs he wants to open/close and determines an event from a set of available events to trigger the specified action; this set of events is based on the reported events by the sensors used in the system.

### 2.4.2 Windows control

The windows will be turned on/off electronically by the remote control or by the central controller commands if certain specified different situations happen. Also, the user of the system can choose the windows he wants to open/close and determines an event from a set of available events to trigger the specified action.

### 2.4.3 Saving electrical equipments

This part of the proposed monitoring and controlling home components sub-system targets the safety of the electrical equipments against different causes for their malfunctioning, and the two causes considered in our solution are the sudden return of a cut electrical current and the long opening of the refrigerator door.

- **Against cut of electricity and its sudden return problems,** a current sensor will detect the cut of electricity and then command the electronic switches at the electrical outlets of all the electrical equipment in the home to isolate them from electric current wire until it detects the return of the current and its stabilization, it will command the switches to supply equipments with the electric current.

- **Against long opening of the refrigerator door,** a light intensity sensor will be put inside the refrigerator besides its lamp, if it detects that the lamp light is open for a specified period it runs the kitchen buzzer and sends a notification message to the remote control.

### 2.4.4 Gas leakage detection, in the kitchen and in the bathroom

Smoke detectors and gas detectors will be used to measure the required type of gases concentration, and warns about that following the same behavior of the windows motion sensors, in addition they will aid to home ventilation as a quick countermeasure through running the electric air hood.

### 2.5 Monitoring Home Structure Health System

A 3-axis accelerometer will be attached to each wall to detect the motion and vibration of the structure due to exposing to dynamic loads originating from a variety of sources such as earthquakes, aftershocks, wind loads, working machines, ground failure, blasts, fatigue, etc.; these sensors send periodically their readings to the central controller to be recorded and graphed. Measuring and recording how a structure responds to these dynamic loads is critical for assessing the safety and viability of a structure, detecting and alarming about a damage before reaching critical state saving money and lives, and enabling engineers to better diagnose and solve any damage if occurred.

### 2.6 Home Plants Care System

Temperature, humidity, and soil moisture sensors can be used to aid in adjusting the suitable conditions for home plants life by displaying the values of these parameters on a single LCD attached to each basin of plants.

### 2.7 Internet Access System

It is to control home from a far distance through TCP/IP connection using the proxy-based architecture approach for providing Internet connectivity while relieving the sensor nodes from the IP stack activities without any disturbance to the network operations. In the proposed system, the base station which is an ordinary radio/processor module is attached to PC or laptop acting as a server provides protocol bridging between the sensor network and the Internet.

The sensor nodes collect information and send it to the base station using their dedicated protocols; the base station then forwards this information using USB or serial connection to the server which takes the responsibility to prepare it and send it to the remote user over the Internet and also receive commands and queries from him to be delivered to the WSN through the attached base station.

With this system, the user can monitor and control the state of different things, doors, windows, lamps, etc. and control them, detect serious events such as an attempt to breaking into the home, gas leakage occurrence, or damage in the home structure requires quick procedure, and also the user can open the front door from a remote place for a trusted person but not from the home inhabitants. This requires the connection to be secured to prevent man-in-the-middle attack.
3. WB-SH SYSTEM SCENARIO

This section will present an installation scenario for the WB-SH. The scenario describes nodes distribution in an example of a flat of common organization, describes the system components, and suggests a communication paradigm for the network. The home plants care system is not considered in the communication paradigm illustration as it doesn’t require wireless communication; also the burglar deception system is dispensed as it is not very beneficial in the existence of the two other systems the entering system and the intruder detection system.

3.1 WB-SH Components Distribution

Figure 2, represents a one level home of area 210 m² consists of a hall partitioned into a large part and a smaller part, large and small balconies, kitchen, large and small bathrooms, and three closed rooms, the walls of the home is made transparent in the figure to show its contents.

The distribution of sensor nodes in the home is explained in the figure, the closed circles and ovals which contain numbers inside represent the sensor nodes. The numbers in the squares, circles, and ovals represent the system components, as shown in table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Representative number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm vein and fingerprint stamps reader</td>
<td>0</td>
</tr>
<tr>
<td>Electronic knob and bolt</td>
<td>1</td>
</tr>
<tr>
<td>Central control unit</td>
<td>2</td>
</tr>
<tr>
<td>Mobile remote control unit</td>
<td>3</td>
</tr>
<tr>
<td>A motion sensor</td>
<td>4</td>
</tr>
<tr>
<td>Front door alarm buzzer</td>
<td>5</td>
</tr>
<tr>
<td>Home part alarm buzzer</td>
<td>6</td>
</tr>
<tr>
<td>Electronic light switch</td>
<td>7</td>
</tr>
<tr>
<td>Electronic door/window opener/closer</td>
<td>8</td>
</tr>
<tr>
<td>Current sensor</td>
<td>9</td>
</tr>
<tr>
<td>Electronic switches at an electrical outlet</td>
<td>10</td>
</tr>
<tr>
<td>Smoke detector and gas detector</td>
<td>11</td>
</tr>
<tr>
<td>3-axis accelerometer</td>
<td>12</td>
</tr>
<tr>
<td>Temperature, humidity, and soil moisture sensors</td>
<td>13</td>
</tr>
<tr>
<td>LCD display</td>
<td>14</td>
</tr>
<tr>
<td>Light intensity sensor</td>
<td>15</td>
</tr>
</tbody>
</table>
From Figure 2, we can deduce that the proposed scenario requires, 23 node contain a 3-axis accelerometer and an electronic switch for electrical outlet, 11 node contain a motion sensor and an electronic door/window opener/closer, 13 node contain a 3-axis accelerometer, an electronic light switch, and alarm buzzer, 4 nodes contain a smoke detector and a gas detector, 3 nodes contain temperature, humidity, and soil moisture sensors connected to LCD display, one node contains light intensity sensor, one node contains current sensor. Also, one special node reads palm vein and fingerprint stamps, opens a knob and a bolt electronically, and contains a motion sensor, a 3-axis accelerometer, and a front door alarm buzzer is needed. The central control unit used is the base station connected to a laptop and also there is a mobile remote control unit used in the scenario.

3.2 WB-SH Components Description

Each sensor node consists of different components as shown in Figure 3; the microcontroller is the Atmel AVR ATmega128 which is a low-power CMOS 8-bit microcontroller. The transceiver is the CC2420 radio transceiver, the node may be powered by a battery or be mains-powered according to the node place, and the sensors/actuators types will be according to the sensor node function, it may be one or a combination of different sensor types, such as an electronic motion detector e.g., a Passive Infrared (PIR) sensor shown in Figure 4.a, an accelerometer shown in Figure 4.b, a detector of gas shown in Figure 4.c, a proximity sensor shown in Figure 4.d, a smoke detector Figure 4.e, etc. An extension interface is used in nodes to allow for connecting external sensors and actuators supporting the separate installation of the different subsystems mentioned before and allowing for the system extension.

For identifying the main raw components required by the proposed system and specifying their approximate prices in a trail to determine the cost of the system, the prices of the components and its required quantities for the whole system are depicted in table 2. From table 2 and after adding an approximate value for the cost of the system fabrication, other
secondary components, system software, and system installation, it could be concluded that the whole system would cost approximately $6000.

![Figure 5 The mobile remote control unit](image)

**Table 2:** The approximate price and quantity for the main components of the WB-SH

<table>
<thead>
<tr>
<th>Component</th>
<th>Approximate price (US $)</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm vein reader</td>
<td>700</td>
<td>1</td>
</tr>
<tr>
<td>Fingerprint reader</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Electronic knob and bolt</td>
<td>55 + 50</td>
<td>1</td>
</tr>
<tr>
<td>A motion sensor</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Front door alarm buzzer</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Home part alarm buzzer</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Electronic light switch</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Electronic door/window lock actuator</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Current sensor</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Electronic switches at an electrical outlet</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>Smoke and gas leakage sensors</td>
<td>7 + 2</td>
<td>4</td>
</tr>
<tr>
<td>3-axis accelerometer</td>
<td>0.6</td>
<td>37</td>
</tr>
<tr>
<td>Temperature &amp; humidity and soil moisture sensors</td>
<td>8 + 1.5</td>
<td>3</td>
</tr>
<tr>
<td>LCD display</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Light intensity sensor</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Rechargeable battery for RC and some mains-powered nodes</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Battery charger</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>AA battery</td>
<td>0.43</td>
<td>20</td>
</tr>
<tr>
<td>AA battery holder case</td>
<td>0.26</td>
<td>33</td>
</tr>
<tr>
<td>Extension interface connector</td>
<td>1.24</td>
<td>57</td>
</tr>
<tr>
<td>ADC</td>
<td>15</td>
<td>57</td>
</tr>
<tr>
<td>DAC</td>
<td>15</td>
<td>48</td>
</tr>
<tr>
<td>Antenna</td>
<td>14</td>
<td>59</td>
</tr>
<tr>
<td>CC2420</td>
<td>6.68</td>
<td>59</td>
</tr>
<tr>
<td>ATMEGA128L</td>
<td>12.9</td>
<td>59</td>
</tr>
<tr>
<td>Keypad</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

This cost may be still considered greater than the reach of some people especially when they are going to pay it in something they consider it as not very important and luxury, but in the same time, the cost of the system is suitable with respect to the offered solutions, specially it includes additional features such as biometrical access control. For example, the Control4 Starter Kit costs $1,000 and it can enable control of a single room, and for adding additional components we should pay more, for home theater more components paid at cost $599, lighting controls ($129 per switch), door locks ($150-350 $) or an intercom unit with camera ($799), so, all-in, outfitting a large home can be quite pricey and the Starter Kit is not for delivering a complete solution [22]. Also as mentioned in [23], the cost of a SH varies depending
on how smart the home is. One builder estimates that his clients spend between $10,000 and $250,000 for sophisticated systems.

3.3 WB-SH Communication Paradigm
First, the different components of the system and the related communications issued by them and their characteristics should be identified. Figure 6, shows the plan view of the considered WB-SH example and the distribution of nodes on it, the Battery-Powered Nodes (BPNs) and the Mains-Powered Nodes (MPNs) exist in each part of the home, also some of the MPNs are equipped with a Rechargeable battery (RMPNs) to remain work as a MPN in the case of electric current cut where this type of nodes can be given special tasks. RMPNs also exist in each part of the home.

![Figure 6: The plan view of the WB-SH example](image)

3.3.1 WB-SH incorporated communications
Starting with the node attached to the front door which is responsible for the electronic knob and bolt (Front Node (FN)) to identify the related communications, the related communications to the FN occur in the following cases: the home entrance process (which are, finger print to BS, palm vein print to BS, BS to bolt, BS to knob, motion and 3-axis accelerometer to BS, and BS to bolt transmissions), in intruding detection (which is, BS to front door buzzer transmission), in exit process (which are, finger print to BS, BS to bolt, motion sensor and 3-axis accelerometer to BS, and BS to bolt transmissions), and on SOS (which is, RC to front door buzzer transmission).

The communications resulted from the windows/doors motion sensors include the communications occur in the following cases: start sensors working (which are, RC to motion sensors and motion sensors to BS transmissions), motion detection (which is, motion sensor(s) broadcast to buzzers and RC), stop sensors working (which are, RC to motion sensors and motion sensors to BS transmissions), and in intruding detection (which is, BS to front door buzzer transmission).

The communications resulted from the electronic door/window lock actuators and electronic light switches include the communications occur in case of opening/closing windows and doors or turning on/off the light switches (which are, RC to electronic switches or actuators and BS to electronic switches or actuators transmissions).

The communications resulted from the current sensor and the electronic switches at the electrical outlets which occur in case of electrical equipments isolation or connection and it is the current sensor to electronic switches transmission.

The remaining communications are, the communications resulted from the 3-axis accelerometer which is the 3-axis accelerometer to BC transmission and the communications resulted from the smoke and gas sensors which include, smoke or gas sensor(s) broadcasts to buzzers and RC, and BS to front door buzzer transmission. Finally, the communication resulted from the light intensity sensor which is the light intensity sensor broadcast to kitchen buzzer and RC.

3.3.2 WB-SH hypotheses
The scenario assumes:
- A fixed BS.
- The number of the room represents the ID of the node responsible for its light switching.
- The BPNs in each room which responsible for windows opening/closing form a group with ID (GID) equals the room number and each one of them has its own ID starting from one and incremented by one. As shown in Figure 6, Room2 is corresponding to GID = 2, i.e., its two BPNs have GID = 2, and they have incremental IDs, ID = 1 and ID = 2.
- The other parts of the home, such as the salon and the kitchen are also considered as rooms with a specified predefined ID (e.g., Hall ID = 7, Salon ID = 8, Kitchen ID = 9, Dining ID = 10, and Corridor ID = 11).
- The BS takes ID equals zero.
- The RC and FN take specific predefined IDs (e.g., 100 and 200).
- The other BPNs and MPNs are numbered with different IDs not important to be known or in other words no need to align their IDs with their entities because no one of them is intended by itself.
- MPN is used in the scenario description to indicate the MPN and RMPN, if the rechargeable nodes are needed to be distinguished the symbol RMPN will be used.

3.3.3 WB-SH communications characteristics and description

The characteristics of the WB-SH incorporated communications have been devised and depicted in table 3. The transmissions’ characteristics considered in the table are, the reporting model, the time of reporting, the communication model, the frequency of occurrence, the reporting period and rate, and the priority; all of these characteristics are important in designing the communication paradigm. The reporting model identifies whether the transmissions are event-driven, command, time-driven, etc. The time of reporting and the frequency of occurrence identify the triggering time of the reporting and how often it occurs. The reporting period and rate identify whether the reporting needs only one transmission or number of transmissions over a period with specific rate. The communication model states if the transmissions are One-to-One (1-1), One-to-Many (1-to-M), Many-to-One (M-to-1), or Many-to-Many (M-to-M). Finally, the priority distinguishes the eligibility extent of transmissions to use the network resources.

Upon the information in table 3 and the above mentioned WB-SH hypotheses, the communication scenario can be as follows:

In the beginning, BPNs broadcast a message using CSMA/CA in a small range covers only one room to save the energy of these nodes which are powered by batteries and in the same time allow them to find one or more MPNs to use them in long-range transmissions constituting multi-hop transmissions, this message contains the node ID, GID (if it has) and type of node from the power point of view (a node as mentioned before may be BPN, MPN, or RMPN). MPNs receive these messages and constitute a table for neighbor nodes contains the ID, the GID (if any), the type of node from the power point of view, and the Received Signal Strength Indicator (RSSI), and identifies a node as the RC if it is.

After a period, all MPNs and of course the BS will announce about their existence. Each MPN will broadcast a message using CSMA/CA in its maximum transmission range because it is powered by the mains no need to save its energy and it is better to perform any transmission in a single-hop as much as possible to reduce the delay, this message contains its ID, its type from the power point of view, and the IDs and GIDs of BPNs it heard from. This continue up to a certain number of times and up to each node constitutes and/or updates its table for neighbor nodes which contains the ID, GID (if any), node type regarding power, RSSI, and identifies the BS and RC.

If a MBN found that the BS is not in its table (not in its range), it sends the message forwarded through multi-hops until it reaches the BS to inform it about its existence, with the next hop being its nearest neighbor.

The BS collects the information received from the MPNs and prepares a schedule. The schedule organizes the awakening of BPNs for receiving only, whereas, they can be turned on in any time to transmit using CSMA/CA with optional acknowledgement. This schedule is used to save the energy of the BPNs from the exhausting in idle listening and overhearing.

The BS dedicates a slot of time to each group of BPNs (BPG) and each BPN not belongs to a group to awake for receiving and gives them the slot duration. The BS gives the FN and the RC a higher rate schedule. Of course, the MPNs remain awake and in contrast the BPNs that only transmit not receive neglect the schedule and remain asleep unless they are transmitting. The BS can update the receive schedule of BPNs in any time. Figure 7, shows a possible arrangement of the rounds of the BPNs and BPGs schedule and the rounds of the schedule of RC and FN. According to these schedules, the maximum delay time of a response to a command sent to a BPN or BPG is computed from equation (1), the maximum delay time of a response to a command sent to the FN or RC is computed from equation (2), and if the command is to more than one BPN or BPG, they respond gradually with maximum response delay computed from equation (3).
<table>
<thead>
<tr>
<th>Transmission type</th>
<th>Reporting model</th>
<th>Time of reporting</th>
<th>Communicati on model</th>
<th>Frequency of occurrence</th>
<th>Reporting period and rate</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Entrance finger print for bolt to BS</td>
<td>Event-driven</td>
<td>Reading a finger print</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>2 Vein print for knob to BS</td>
<td>Event-driven</td>
<td>Reading a palm vein</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>3 BS to bolt &amp; BS to knob</td>
<td>Event response</td>
<td>Consecutive responses to 1 &amp; 2</td>
<td>1-to-1</td>
<td>High</td>
<td>From door opening up to door closing with high reporting rate</td>
<td>High</td>
</tr>
<tr>
<td>4 Front door motion and accelerometer sensors to BS</td>
<td>Event-driven</td>
<td>When the door opened</td>
<td>1-to-1</td>
<td>High</td>
<td>From door opening up to door closing with high reporting rate</td>
<td>High</td>
</tr>
<tr>
<td>5 BS to bolt</td>
<td>Event response</td>
<td>After a period from door closing</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>Medium</td>
</tr>
<tr>
<td>6 BS to front door buzzer</td>
<td>Event response</td>
<td>Intruding detection</td>
<td>1-to-1</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>7 Exit finger print for bolt to BS</td>
<td>Event</td>
<td>Reading a finger print</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>8 BS to bolt</td>
<td>Event response</td>
<td>In response to 7</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>9 Front door motion and accelerometer sensors to BS</td>
<td>Event-driven</td>
<td>When the door opened</td>
<td>1-to-1</td>
<td>High</td>
<td>From door opening up to door closing with high reporting rate</td>
<td>Medium</td>
</tr>
<tr>
<td>10 BS to bolt</td>
<td>Event response</td>
<td>After a period from door closing</td>
<td>1-to-1</td>
<td>High</td>
<td>Once</td>
<td>Medium</td>
</tr>
<tr>
<td>11 RC to front door buzzer</td>
<td>Command</td>
<td>On SOS</td>
<td>1-to-1</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>12 RC to motion sensors</td>
<td>Command</td>
<td>Any time of the day</td>
<td>1-to-M</td>
<td>Medium</td>
<td>Once</td>
<td>Low</td>
</tr>
<tr>
<td>13 Motion sensors to BS</td>
<td>Command response</td>
<td>When start working</td>
<td>M-to-1</td>
<td>Medium</td>
<td>Once</td>
<td>Low</td>
</tr>
<tr>
<td>14 Motion sensor(s) broadcast (to buzzers and RC)</td>
<td>Event-driven</td>
<td>When doors or windows move</td>
<td>M-to-M or 1-to-M</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>15 RC to Motion sensors</td>
<td>Command</td>
<td>Any time of the day</td>
<td>1-to-M</td>
<td>Medium</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>16 Motion sensors to BS</td>
<td>Command response</td>
<td>When stop working</td>
<td>M-to-1</td>
<td>Medium</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>17 BS to front door buzzer</td>
<td>Event response</td>
<td>Intruding detection</td>
<td>1-to-1</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>18 RC to electronic openers/closers</td>
<td>Command</td>
<td>Any time of the day</td>
<td>1-to-M</td>
<td>Medium</td>
<td>Once</td>
<td>Low</td>
</tr>
<tr>
<td>19 BS to electronic openers/closers</td>
<td>Command or time-driven or event-driven</td>
<td>Any time of the day</td>
<td>1-to-M or 1-to-1</td>
<td>Medium or low or rare</td>
<td>Once or through a defined period</td>
<td>Low</td>
</tr>
<tr>
<td>20 Current sensor to electronic switches</td>
<td>Event-driven</td>
<td>At cut or return of electricity</td>
<td>1-to-M</td>
<td>Low</td>
<td>Once</td>
<td>Medium</td>
</tr>
<tr>
<td>21 3-axis accelerometers to BC</td>
<td>Periodically</td>
<td>Periodic time of the day</td>
<td>M-to-1</td>
<td>Low</td>
<td>In normal conditions: once every day. If a threshold exceeded: high reporting rate</td>
<td>High</td>
</tr>
<tr>
<td>22 Smoke detector and gas detector (to broadcast buzzers and RC)</td>
<td>Event-driven</td>
<td>On gas leakage or fire detection</td>
<td>M-to-M or 1-to-M</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>23 BS to front door buzzer</td>
<td>Event response</td>
<td>In response to 22</td>
<td>1-to-1</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
<tr>
<td>24 Light intensity sensor to kitchen buzzer and RC</td>
<td>Event-driven</td>
<td>When the refrigerator still opened from a period</td>
<td>1-to-M</td>
<td>Rare</td>
<td>Once</td>
<td>High</td>
</tr>
</tbody>
</table>
Figure 7 Time schedules, (a) BPNs and BPGs schedule, (b) RC and FN schedule

Max. response delay of BPN or BPG = (BPNs no. + BPGs no. - 1) × slot time
(1)
Max. response delay of FN or RC = slot time of the FN and RC schedule
(2)
Max. gradual response delay of BPNs or BPGs = slot time of the BPNs and BPGs schedule
(3)

Then, the BS prepares a message with these schedules and a tidy list of MPNs it heard from according to their distances from it (it arranges the nodes deliver their messages to it through multi-hops at the end of the list according to the time of message reception), and sends this message to the nearest MPN directly.

Each node receives this message stores the awake period (slot time) and the dedicated slot number related to any BPN or BPG from its neighbors in the neighbors table, the RC schedule whether or not it is from its neighbors, and also the tidy list of MPNs. Then, it sends these sub-schedules to any BPN or BPG from its neighbors in one message and indicates to them the start time to begin to compute the beginning of their slots (the reference time ($t_{ref}$)) and indicates the length of the whole schedule ($t_{sched}$). Because nodes are not synchronized, the $t_{ref}$ is not put in the message, but an indication to it is put instead through the reference time offset ($t_{ref}$-offset) field which contains an approximation to the offset from the $t_{ref}$ of the time at which the next hop node will receive the message.

These neighbors when receive the schedule, each one starts to work with its slot number and duration from the time it received the message, because this message indicates $t_{ref}$-offset = 0 (i.e., the time of this message reception will be taken as the $t_{ref}$).

After that it forwards the original message to its next candidate in the tidy list of MPNs after putting an indication of when its BPGs received the schedule because this time as mentioned before will be used as a start time for all nodes whether mains or battery-powered to compute the start of slots, i.e., it sets $t_{ref}$-offset = the estimated packet delivery delay ($t_d$) = packet transmission delay + packet propagation delay.

The next MPN when receives the message it does the same behavior as the last said, except that if it found a BPG or a PBN from its neighbors is already received its specific schedule, it only stores this schedule and doesn’t send it. And of course if it sends the schedule, it sends the appropriate estimated $t_{ref}$-offset. When the next MPN receives the message it does the same behavior as the message sender, and so on. Figure 8, shows the schedule propagation and $t_{ref}$-offset values, assuming the MPNs tidy list is [1, 4, 3, .......]. Each node computes the value of $t_{ref}$ from equation (4).

$$t_{ref} = current\ time - t_{ref}\ offset$$
(4)

If a node found that the Current time < $t_{ref}$ + slot no. × slot time, it computes the start of its first slot from equation (5).

First slot start time = $t_{ref}$ + (slot no. × slot time)
(5)

If a node found that the current time > $t_{ref}$ + slot no. × slot time, i.e., it missed its first slot(s), it locates its next slot start using equation (6).

Slot start time = ($t_{ref}$ + (slot no. × slot time)) + (no. of schedule rounds lost × $t_{sched}$)
(6)
Once the node locates and reaches a slot, it schedules the subsequent slots beginnings using the equation (7).

\[ \text{Slot start time} = \text{current slot start time} + t_{\text{schd}} \]  

(7)

After that, each BPN knows when it should be awake to receive and each MPN knows when its neighbor BPGs and BPNs are awake. MPNs can relax after an agreement among them one or more of its neighbor BPGs for one or more slots according to some conditions such as a command for them just received and it is not probable to receive another command soon.

In the following, will be presented how the transmissions of commands and data are performed and how the rest of the network setup is done by learning paths to destinations. With respect to how the 1-to-1 and M-to-1 communications occur, while the following different considered cases exist in the used scenario or not, can be explained as follows:

- In case of the destination is the BS
  - If the source node is mains-powered: in case the BS is its neighbor, it sends with single-hop directly to it, but if it didn’t find the BS in its neighbor list, it sends the message directly to the nearest mutual MPN neighbor to the BS, then this node forwards the message to the BS, in case it didn’t find a mutual neighbor it forwards the message to its nearer MPN neighbor.
  - If the source node is battery-powered: it sends to the nearest MPN, then the MPN follows the same just mentioned behavior.

The operations of the just mentioned case are illustrated in Figure 9.

**Figure 8** Schedule propagation illustrative example

**Figure 9** Transmissions flow in case of the destination is the BS
• In case of the destination is a MPN
  - If the source node is a MPN: in case the destination is its neighbor, it sends with single-hop directly to it, but if it didn’t find the destination in its neighbor list, it learns from the tidy list which neighbor may be the nearest to the destination and sends it the message, then this node forwards the message to the destination, otherwise if it didn’t find a mutual neighbor it forwards the message to its nearer neighbor.
  - If the source node is battery-powered: it sends it to the nearest MPN, and then the MPN follows the same just mentioned behavior.
  - If the source node is the BS: it sends directly to the destination or the node that forwarded this destination message to it.

In case of the destination is a BPN or BPG
  - If the source node is a MPN: in case the destination is from its neighbors and it is in the awakening slot now, it sends to it directly, but if it isn’t in the awakening slot, it stores the message for it until becoming awake. In case the destination is not from its neighbors, it searches its table for a node responsible for this destination (if more than one found, it chooses the nearest) and sends it directly the message, if such a node is not found in the table, it sends the message to the nearest MPN, in case this node also doesn’t have the destination node in its neighbors or a responsible node for it, it follows the same behavior of the first node, this continues until a responsible node for this destination found, then if this destination node found that it is the first time to receive a message from this source through this neighbor, it sends a reply message to the node that forwards to it the received original message, then this node forwards the reply message to the original message source directly if it is in its range or to the node that forwards to it the original message, in this case, the node that receives the reply message does as its previous node did, until the reply message received by the source of the original message. Each node receives a reply message records its sender as the route for the BPG or the BPN intended by the original message. So, any MPN learns in this way the route to this BPN or BPG destination and uses it in the subsequent communications. So, if a MPN wants to send to a BPN or a BPG and it knew from previous communication the next hop for that destination it sends to it directly. If a link to a node in this path is lost, the node lost the link does the same thing as the first time it sent or forwarded a message for this destination and learns another route for this destination used for such subsequent cases. Each node sends the data to its neighbor BPNs or BPGs members when they awake, and stores any packets intended for each BPN or BPG until it awakes in a priority queue considers the communication priorities in table 3. Also, in the case of the destination is a MPN, when it receives a forwarded message for the first time from a source through the neighbor forwarded it, it sends a reply message in the previously mentioned way to allow the source of the message or the MPN sent the message on behalf of a BPN to establish a path to it, but, the source node selects between this established path to this destination and a path from which it received message from this destination previously with respect to the minimum number of hops.
  - If the source node is battery-powered: it sends the message to the nearest MPN, and then the MPN follows the same just mentioned behavior.
  - If the source node is the BS: it knows the responsible nodes for each BPN or BPG, so it sends it the message directly or through multi-hop beginning from the node that forwarded in the beginning the message from this node.

The sequence of transmissions in case of the destination is a BPN or BPG is shown in Figure 10.

The RC is a battery-powered node, it works like any BPN, but because it is mobile, it broadcasts in the range of a BPN a message each time it wakes up to inform the new neighbors about its existence to become responsible for it. The old RC neighbors conclude that it moves away from them and they are no longer responsible for it when they lost its announcement message through two subsequent awake periods. On the other hand, any new responsible node for the RC sends it back a message to update its neighbors table.
The 1-to-M and M-to-M communications are achieved through flooding in a small range (room range) to reduce interference and collisions and by using CSMA/CA, any node forwards a message shouldn’t forward it again and drops it.
Any time a node needs to transmit a message, it transmits it using CSMA/CA and optional acknowledgement only if the first transmission attempt is failed (or in more accurate words the node decides whether to use CSMA/CA and acknowledgement or not according to the message type and its characteristics such as the time of reporting, frequency of occurrence, and the reporting model, period and rate).

4. NEXT GENERATION SH

It may be important or convenient, that the machine “knows” who is using it. This allows automatic adaptation to the needs of people, but also tracking of their actions and reacting in the case of misuse [24] and this can be achieved by biometrics.
Biometric recognition or, simply, biometrics refers to the automatic recognition of individuals based on their physiological characteristics, e.g., fingerprints, hand geometry, vein, face, ear, etc., and/or behavioral characteristics e.g., gait, signature, keystrokes, etc. [21]. The methods for personal identification by each of these characteristics have their advantages and limitations; among them the vein recognition offers an array of advantages over the other biometric techniques including, ease of feature extraction, spoofing resistant, high accuracy, vein patterns are much less susceptible to many external factors, user friendliness, and the rapid verification against a stored reference template providing a very fast and robust biometric authentication. This describes why the vein recognition is used for the entering sub-system in the proposed WB-SH system in this paper and the palm veins specially is used as it is the most suitable to the door knob for more convenience and for decreasing the taken actions for entering such that it appears like the user only turns the knob and enters. Figure 11, is a comparison illustrates that vein pattern recognition is a very difficult biometric modality to circumvent.

Figure 10 Transmissions flow in case of the destination is a BPN or BPG

Figure 11 Difficulty in spoofing vein patterns [21]
But this automatic adaptation can be enhanced and extended behind the customization of a specific machine to the user need to the customization of the whole environment to the user preferences. By more employing biometrics in the SH system, a profile for each inhabitant will be made characterized by his finger and palm vein stamps in addition to other personal stamps, such as iris recognition and voice, this profile includes settings and permissions specific to the profile owner.

With respect to office room customization, by reading the fingerprint when the person catches the mouse or put his finger in a dedicated part on the desk, not only the computer and the specified programs such as the person mail box opens to him, but the desk light turned on with an illumination level custom to this person, well as the air conditioner, windows and curtains state, the height level of the office chair, the preferred music, perfuming the room with a special perfume, and the electronic drink maker starts to bring his preferred drink; this also can be combined customization with respect to time of the day of the fingerprint reading. These actions are preset to default settings when the computer shut down and can be preset, repeated, or changed using software commands.

With respect to bed room customization, the bed room can be shared by your two daughters or your two sons, in the same time the room space and the exclusiveness are saved. Each person will have his bed, his wardrobe, his dresser, and his desk in the same room. The person by his fingerprint or hand geometry print can turn the wardrobe from vertical position to horizontal position so that it converted to a bed with a light dimmed to suitable luminance where the wardrobe is the back of the bed, and when the bed occupied the wardrobe returns to its vertical position after a period from its occupation, also the wardrobe opened and closed with the person specific print.

By using face recognition, when the person set on his desk, the two halves of the disk are opened such that the drawers are in the front of them, the desktop and the desk back are elongated, and one half of the desk outputs a mirror and works as a dresser. In the bathroom, the faucet can be opened with a suitable combination of warn and cold water to its user. With face recognition, specific TV channels are allowed for specific persons. Doors, windows and drawers contain serious thing such as knife and medicine are prohibited from children. An alarm can awaken the person in a specified time in the morning, and after his identity is authenticated, the bathroom is warmed and his prepared shower is prepared for it while the drink maker machine and the sandwich maker machine prepare his breakfast and the whole home environment is customized for his waking.

By using microphone sensors and Speech Recognition, the person can give a voice order from his place near or far to the window to open or close, to the lamp to switch on or off, etc. Also in combination with Speech Recognition, the voice can be used as a stamp for persons using voice recognition which refers to finding the identity of "who" is speaking, rather than what he is saying, when a person orders the air conditioner to open, it opens with a customized level specific to the ordering person.

This integration of WSN and biometrics can be considered as a system for welfare for ordinary persons with respect to a lot of its applications, but it is necessary for elders and persons with disabilities in a lot of its applications, rather than the valuable benefits that resulted from this integration, such as time and exclusiveness saving, comfort, sharing of resources, and safety of children.

5. CONCLUSIONS AND FUTURE WORK

This paper proposes a new design for the SH by introducing the Wireless Biometric Smart Home (WB-SH) system which integrates two emerging technologies, the wireless sensor network technology and the biometric technology. The paper also proposes a new communication paradigm for the WB-SH. WB-SH offers a complete solution for the whole home includes a number of sub-systems which are the entering system, the burglar detection and deception systems, monitoring and controlling home components system, monitoring home structure health system, home plants care system, and Internet access system, so that it is not necessary to buy and install the whole system. The whole WB-SH system offers a cost convenient solution relative to the currently offered solutions’ costs (the whole WB-SH system cost is determined to be approximately $6000); also the system is extensible and easy in installation and maintenance. Other features of the WB-SH is that it is designed to be capable of incorporating in a building automation system, it can be applied to other places rather than the home environment such as offices and clinics, and it is suitable to different areas. The WB-SH enhances the security by using two door locks, an electronic knob and an electronic bolt, the two locks is controlled using biometrics to provide easy and very secure entering process. The palm vein specially is used because the vein pattern recognition is a very difficult biometric modality to circumvent. With the WB-SH, the home can be controlled locally using a remote control or an application on a PC or laptop, or remotely through the Internet.

The WB-SH communication protocol is designed such that, it takes the advantage of the fixed places of nodes and the placement of some them at or near the electrical mains to make them mains-powered and accordingly load them with heavy tasks in a way improving the network performance, saves the energy of the nodes that are battery-powered
by employing a sleeping schedule for them, considers the delay of response to an event or command, considers the case of electricity cut. The WB-SH still has the limitation of assuming a fixed BS, also the FN frequently transmits data, needs to be awake for considerable period in each communication, and its buzzer should receive a SOS alarm immediately and accordingly it is given a high rate sleep schedule, all this and it is battery operated, so its lifetime is critical; this can be circumvented by installing it in a place such that it can be powered by the electricity mains. Also, this paper discussed how the deep integration between the wireless sensor network and the biometrics can improve SH design and customization and represent a trend for future research.

REFERENCES


AUTHOR

Basma M. Mohammad is an assistant researcher in Computers and Systems Department at the Electronics Research Institute (ERI) in Egypt. In May 2005, she completed her B.S. in Computers and Control Science, Faculty of Engineering, Zagazig University. During the 2005-2006 year, she joined the Professional Training Project (Network Management & Infrastructure (Tivoli) Track) which is organized by the Egyptian Ministry of Electricity and Information Technology. In 2007 year, she occupied the position of research assistant at Electronics Research Institute. Since 2011, she occupied her current position. Basma Mamdouh has published 3 papers and 1 book chapter. Her current research interests focus on Networks especially on Wireless Sensor Networks (WSN). Now, she is studying for Ph.D. degree.

S. Abd El-kader has her MSc. & PhD degrees from the Electronics & Communications Dept. & Computers Dept., Faculty of Engineering, Cairo University, at 1998, & 2003. Dr. Abd El-kader is an Associate Prof., Computers & Systems Dept., at the Electronics Research Institute (ERI). She is currently supervising 3 PhD students, and 10 MSc students. Dr. Abd El-kader has published more than 25 papers, 4 book chapters in computer networking area. She is working in many computer networking hot topics such as; Wi-MAX, Wi-Fi, IP Mobility, QoS, Wireless sensors Networks, Ad-Hoc Networking, realtime traffics, Bluetooth, and IPv6. She is an Associate Prof., at Faculty of Engineering, Akhbar El Yom Academy from 2007 till 2009. Also she is a technical reviewer for many international Journals. She is heading the Internet and Networking unit at ERI from 2003 till now. She is also heading the Information and Decision making support Center at ERI from 2009 till now. She is supervising many automation and web projects for ERI. She is supervising many Graduate Projects from 2006 till now. She is also a technical member at both the ERI projects committee and at the telecommunication networks committee, Egyptian Organization for Standardization & Quality since February 2007 till 2011.

Mahmoud Fakhreldin was born in Giza, Egypt, in 1968. He received the B.S. degree in automatic control from the University of Minufia in 1991 and the M.Sc. and PhD degree in Computer Engineering, from Electronics and Communications Department, Cairo University, Faculty of Engineering, in 1996 and 2004 respectively. He works as an associate professor of computer science at the Electronics Research Institute. He has also worked at the Faculty of Engineering, Abha, KSA and different universities in Egypt. He works as a consultant at the ministry of communications and information technology, Egypt, 2004 – till now and collects different experiences in information technology while working in different governmental organizations in Egypt. His areas of interest are Evolutionary Computation, Advanced automatic control, image processing and biomedical engineering.