

Decentralization of Services Through Three Tiers in Wireless Body Area Networks

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Abstract—The Wireless Body Area Network (WBAN) contains a set of sensors, placed in the patient’s environment, to detect the vital signs and transmit the results towards the relevant services that interact in urgent cases. The present work exposes a functional WBAN architecture formed by three layers: closest, intermediate and farthest. The closest layer senses the chemical and biological signs. If the case is normal, or it can be locally regulated, the service stops there; else the intermediate service, namely the local hospital, is consulted to make treatments. Therefore, the patient will be transported into the hospital for examinations. If this condition is established the processus stopped there, otherwise, the request of help from an outside hospital becomes necessary. This request passes through a manager that supervises a network of hospitals and looks for a free place to welcome the patient. After the localization of a hospital, its coordinates will be forwarded into the customer hospital, for transporting the patient. The simulation results show that this design increases the patient’s probability of healing and maximizes the use of the available resources, relative to the centralization of services at a single layer or at two layers.

Index Terms—WBAN, decentralization of services, centralization of services, probability of healing, resource optimization.

I. INTRODUCTION

The WBAN is defined by the IEEE 802.15.6 and the IEEE 802.15.4j [1] as a collection of distributed sensors: around, on or in the human body to collect data. The sensed information is converted, stored, processed and transmitted towards the health service, to inform or request the intervention. This technology with a remote and automatic service, clean and easy, has revolutionized the services and infrastructure of hospitals, ambulances and homes.

The increased traffic via this network, prolongs the time for transferring data, to the concerned services. First aid may therefore arrive late; sometimes after the deterioration of the patient’s condition and the desperation to heal. Consequently, wait time becomes an essential parameter to indicate the performance of WBAN. Occasionally, the consulted hospital can be saturated, so no intervention can be performed; while other hospitals offering the same services are free. This situation shows both: the limitation of the policy of centralizing services in a single resource, and the importance of optimizing the resources available in a network. Highlighting, the IEEE

802.15.6 standardization emphasized the importance of real-time communication and resource optimization, to save the patient health [1]. For instance, an emergency packet is sent to the health services to indicate the patient’s critical condition, in order to intervene [2]. D.Ousmane et al. [3] studied the minimization of the communication delay, by proposing both: an architecture and a query processing algorithm that are combined with cloud services and statistical modeling techniques. As well, the problem of resource optimization had found its place in the literature [1], [4]. The contribution of [4] was based on that of [1], after developing a prioritized resource allocation algorithm, to share the limited communication channel between multiple WBANs.

In summary, minimizing the communication delay [1], [3], prioritizing the emergency package [2] or optimizing the communication resource [3] are important for serving the patient’s life. For our part, we take advantage of the WBAN architecture to increase the patient’s probability of recovery. For this goal, we design a functional WBAN architecture, formed by three layers: closest, intermediate and farthest. Each one performs its tasks to enhance the patient’s condition; in the case of the inability, it requests the help from the upper adjacent layer, and so, until the good health or the incapacity of the global service. The tasks of these layers are distributed as follows: the closest layer is occupied to collect the vital signs using sensors, to analyze the results by smart devices, and to regularize the local cases using actuators. When this layer fails to solve the problem, the middle layer takes care of the patient. First, an equipped ambulance, accompanied by a health team, makes a site visit of the patient. After the preliminary treatments, if the patient’s condition is regulated, the service stops there; otherwise, the patient will be transported to the local hospital; in order to make exhaustive diagnoses and cares. Despite its efforts, sometimes, this hospital remains helpless against some situations. Therefore, it will be obligated to ask for an outside help. The request for help is intercepted by the hospital network manager, which is looking for a free place in the network. Once this place has been found, the coordinates of the hospital concerned will be transmitted to the intermediate layer, to transport the patient to the said hospital. Via this architecture, we decentralize services through three layers. This is why, we are improving the patient’s probability of recovery rather than centralizing services at one or at two layers.

The rest of this work is organized as follows: in section II, we present some related works based on the resource optimization and delay minimization. We process by levels

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in section III, to enhance the probability of healing and optimize the hospital network. In section IV, we model the probability of healing, and we analytically evaluate our model relative to centralization of services at one or at two levels. The simulation results are exposed in section V. Finally, we conclude in section VI.

II. RELATED WORKS

The optimization of energy, time and communication infrastructure had attracted enormous works. A hybrid autonomic resource provisioning framework is proposed in [5]. This approach combined between autonomic computing and queuing model. The simulation results showed an amelioration in terms of resource utilization and response time, by at least 26% and 49%, respectively, compared with other methods. To study the effect of sensor communication on the energy consumption and throughput, the authors of [6] proposed two protocols: Optimized Cost Effective and Energy Efficient Routing protocol (OCER), as well as an extended-OCER. In another study [7], a scheme leverages Lagrangian duality theory is designed, to find efficient trade-off among energy consumption, network cost, and vital signs distortion, for delay sensitive transmission of medical data. The optimal trade-off between energy efficiency and QoS requirements, while providing 15% savings the energy-cost-distortion utility function, compared to solutions based on equal bandwidth allocation. In order to maintain Mobile Data Collectors (MDC)-relay networks, the paper [8] proposed a self-organizing and an adaptive Dynamic Clustering Multiple MDC. This solution is based on dividing the network into well-delimited clusters, called Service Zones. The experimental performances improved the packet delivery ratio and end-to-end delay by up to 10%. The energy consumption, energy balancing and network lifetime, each one by up to 51%. A Superframe Overlapping Scheduling (SOS) based on beacon shifting and active superframe interleaving techniques used the IEEE 802.15.6 standard, was developed by [9]. The authors parameterized the required service rate and maximum packet inter-arrival time for each WBAN. The SOS conception improved bandwidth utilization and guaranteed QoS, according to individual WBAN task deadlines. With the aim to study the relation between the data packet transmission delay and the system dynamics, as well as, the impact of the stability regions and bifurcation scenario, the work developed in [10], proposed a delayed e-epidemic model and explored the dynamic systems. The paper [11] summarized characteristics of Intermittently Connected Delay-Tolerant Wireless Sensor Networks (ICDT-WSNs) and their communication protocol requirements, also examined the communication protocols designed for WSNs in the recent years from the perspective of ICDT-WSNs. To solve the issues in reconstruction computation complexity of WBAN, the work of [12] developed compressed sensing for compressing and collecting signals in real-time. The evaluation of results showed that the improvement of real-time performance is contributed by the application of binary permutation block diagonal matrix. The security issues are treated in [13] to ensure the sensor data acquisition and transmission protocols. The main security features are

described and compared in the context of a secure eHealthcare system. In the other side, the work developed in [14] proposed an energy efficient wireless telemonitoring scenario of heart patients through ZigBee, under variable load conditions. This method is compared with different percentage of duty cycle on the basis of energy consumption parameter.

The WBAN architecture has attracted the attention of several researchers [15], [16], [17]. L.Ahmed et al. [15] proposed an architecture for collecting and accessing large amount of data that is generated by medical sensor networks. This architecture overcame enormous challenges, and made easy information sharing, between healthcare professionals in normal and emergency situations. On the other side, A.Bandar and F.Hacene [16] detailed the features hardware and software for mobile health-monitoring platform.

These related works were aimed at minimizing the transmission delay and maximizing the resource use. In our approach, we emphasize the importance of the adopted architecture to increase the probability of healing and optimize the available resources of a hospital network.

III. OUR APPROACH AND FUNCTIONAL ARCHITECTURE

Regarding their location to the patient, the overall service is made up of three layers: closest, intermediate and farthest. When a lower service fails to establish the patient's condition, it will ask for help from the upper adjacent service; until the regulation of the anomaly, or the inability of the whole service. In the next, the function of each level will be detailed.

A. Closest Service

1) *Components*: This service is the closest to the patient. Its principal components are: sensors, hub, smart device and regulators (Fig.1). The sensors detect vital signs, convert them

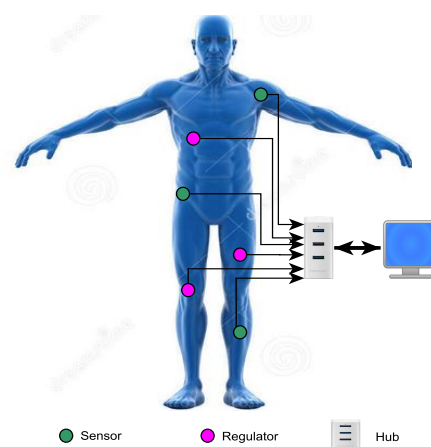


Fig. 1. BAN

into physical signs and finally transmit the signals obtained to the hub. This latter, collects all signals and transmits the results as a vector to the smart device, to make treatments, based on the following model:

2) *Operation of the Smart Device*: Let W be the received vector, such as:

$$W = (w_1, \dots, w_j, \dots, w_n) \quad (1)$$

Each component w_j has a measurement unit u_j . Thus, we put:

$$w_j = v_j \times u_j \quad (2)$$

Where v_j is a numerical value. The normal state relating to a vital sign j , is indicated by the belonging of w_j to a confidence interval:

$$CI_j = [min_j \times u_j, max_j \times u_j] \quad (3)$$

The overall normal state is ensured by the belonging of each w_j to its confidence interval. To specify this membership, we calculate a scalar S_j which is unitless:

$$\begin{aligned} S_j &= \frac{(max_j \times u_j - v_j \times u_j)(v_j \times u_j - min_j \times u_j)}{(max_j \times u_j - min_j \times u_j)^2} \\ &= \frac{(max_j - v_j)(v_j - min_j)}{(max_j - min_j)^2} \end{aligned} \quad (4)$$

As a result, we have the following equivalences:

$$w_j \in CI_j \Leftrightarrow S_j \geq 0 \Leftrightarrow |S_j| = S_j \Leftrightarrow |S_j| - S_j = 0 \quad (5)$$

Then, we can define an elementary indicator e_j based on S_j :

$$e_j = |S_j| - S_j \quad (6)$$

Finally, we establish a global indicator:

$$g = \sum_{j=1}^n e_j \quad (7)$$

While each e_j is unitless, g is well defined. Then, we have:

Corollary 1: The patient is in good overall condition if and only if $g = 0$.

If g is not zero, an abnormal state requires an intervention. To specify the service involved, the smart device uses the vector W , whose components will be classified into two families: L and I , for locally adjustable vital signs and others intermediately, respectively. As a result, the vector W becomes:

$$W = (L, I), \quad L = (w_1, \dots, w_i), \quad I = (w_{i+1}, \dots, w_n). \quad (8)$$

Accordingly, the smart device processes as follows:

- 1) Calculate the value of g : if $g = 0$, there is no problem, else;
- 2) Browse the components of L : if there is a non-zero component, the adjusted value and the concerned regulator must be specified, else;
- 3) Ask for help from the intermediate service (Fig.3).

B. Intermediate Service

The intermediate service is the local hospital that monitors a group of patients around its territory. At this level, a service categorization is performed. If the state can be intermediately treated and the hospital is not yet saturated, a visit of the patient will be carried out. After that, if the good state is established, the service is completed here; if not, the move of the patient into the hospital becomes necessary, to perform exams and treatments. Following these operations, in the case of regulation of the state of health, the task is accomplished here. Otherwise, a rescue message is forwarded to the hospital network manager. (Fig. 3).

C. Farthest Service

The hospital network is administered by a manager that communicates with all hospitals, in order to provide service to the patient (Fig.2).

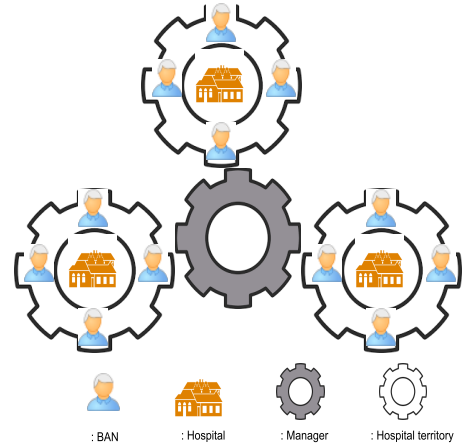


Fig. 2. Operation of the hospital network manager

After receiving a help request from the intermediate service, the network manager looks for a free place in a set of hospitals, to welcome the patient. If such place is found, a message indicating the receptive hospital coordinates will be sent to the intermediate service, to move the patient. Otherwise, a message mentioning the absence of service is transmitted, and the service is stopped there (Fig.3).

IV. PERFORMANCES

A. Probabilities of Healing

Simply, our model proceeds as follows:

- 1) If the actuators adjust the patient's condition, that is fine; otherwise,
- 2) the patient will be treated by local hospital. If the latter gives a good result, the service stops there; else,
- 3) the patient will be greeted by the hospital network manager which selects an available hospital, to treat the patient's anomaly.

To identify the layer that brings good health to the patient, we define three random variables: X_1 , X_2 and X_3 that correspond to regulator, local hospital and hospital network, respectively. Each of them follows a Bernoulli law, thus we have equation (9):

$$X_i = \begin{cases} 1 & \text{if the patient cures at level } i, \\ 0 & \text{if not, } \forall i \in \{1, 2, 3\}. \end{cases} \quad (9)$$

Therefore, we can write:

$$p(X_i = 1) = p_i, \quad p(X_i = 0) = 1 - p_i, \quad \text{with } p_i \in [0, 1].$$

The probability of healing by our model or decentralization of services, can be defined as follows:

$$\begin{aligned} p_{ho} &= p(X_1 = 1) + p(X_1 = 0, X_2 = 1) \\ &\quad + p(X_1 = 0, X_2 = 0, X_3 = 1) \\ &= p_1 + (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \end{aligned}$$

B. Comparison between Centralization and Decentralization of Services

1) Centralization at one level:

- At the 1st level:

The probability of healing at this level is p_1 .

$$\begin{aligned} p_{ho} - p_1 &= (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &= (1 - p_1)(p_2 + (1 - p_2)p_3) \\ &= (1 - p_1)(p_3 + (1 - p_3)p_2) \geq 0 \end{aligned} \quad (10)$$

- At the 2nd level:

The probability of healing at this level is p_2 .

$$\begin{aligned} p_{ho} - p_2 &= p_1 + (1 - p_1)p_2 - p_2 + (1 - p_1)(1 - p_2)p_3 \\ &= p_1 + (1 - p_1 - 1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &= p_1 - p_1p_2 + (1 - p_1)(1 - p_2)p_3 \\ &= (1 - p_2)(p_1 + (1 - p_1)p_3) \\ &= (1 - p_2)(p_3 + (1 - p_3)p_1) \geq 0 \end{aligned} \quad (11)$$

- At the 3rd level:

The probability of healing at this level is p_3 .

$$\begin{aligned} p_{ho} - p_3 &= p_1 + (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 - p_3 \\ &= p_1 + (1 - p_1)p_2 + [(1 - p_1)(1 - p_2) - 1]p_3 \\ &= p_1 + (1 - p_1)p_2 + [(1 - p_1)(1 - p_2) - 1]p_3 \\ &= p_1 + (1 - p_1)p_2 + [-p_1 - p_2 + p_1p_2]p_3 \\ &= p_1 + p_2 - p_1p_2 - p_1p_3 - p_2p_3 + p_1p_2p_3 \\ &= p_1 - p_1p_3 + p_2 - p_2p_3 - p_1p_2 + p_1p_2p_3 \\ &= p_1(1 - p_3) + p_2(1 - p_3) + p_1p_2(-1 + p_3) \\ &= (1 - p_3)(p_1 + p_2 - p_1p_2) \\ &= (1 - p_3)(p_1 + (1 - p_1)p_2) \\ &= (1 - p_3)(p_2 + (1 - p_2)p_1) \geq 0 \end{aligned} \quad (12)$$

From equations : (11), (12) and (13), we deduce that:

$$\begin{aligned} p_{ho} - p_i &= (1 - p_i)(p_j + (1 - p_j)p_k) \geq 0, \\ \forall i \neq j \neq k, \quad \text{and } (i, j, k) &\in \{1, 2, 3\}^3 \end{aligned} \quad (13)$$

- Expression of p_{ho} as a function of $p_i, \forall i \in \{1, 2, 3\}$:
Form equation (14), and after simplification, we have:

$$\begin{aligned} p_{ho} &= [p_j + (1 - p_j)p_k] + [(1 - p_j)(1 - p_k)] p_i \\ \forall i \neq j \neq k, \quad \text{and } (i, j, k) &\in \{1, 2, 3\}^3 \end{aligned} \quad (14)$$

2) Centralization at Two Levels:

- At the 1st and 2nd level:

The probability of healing at these levels is:

$$p_{12} = p_1 + (1 - p_1)p_2.$$

$$\begin{aligned} p_{ho} - p_{12} &= p_1 + (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &\quad - p_1 - (1 - p_1)p_2 \\ &= p_3(1 - p_1)(1 - p_2) \geq 0. \end{aligned} \quad (15)$$

- At the 1st and 3rd level:

The probability of healing at these levels is:

$$p_{13} = p_1 + (1 - p_1)p_3.$$

$$\begin{aligned} p_{ho} - p_{13} &= p_1 + (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &\quad - p_1 - (1 - p_1)p_3 \\ &= (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &\quad - (1 - p_1)p_3 \\ &= (1 - p_1)p_2 + (1 - p_2 - 1)(1 - p_1)p_3 \\ &= (1 - p_1)p_2 - p_2(1 - p_1)p_3 \\ &= p_2(1 - p_1)(1 - p_3) \geq 0. \end{aligned} \quad (16)$$

- At the 2nd and 3rd level:

The probability of healing at these levels is:

$$p_{23} = p_2 + (1 - p_2)p_3.$$

$$\begin{aligned} p_{ho} - p_{23} &= p_1 + (1 - p_1)p_2 + (1 - p_1)(1 - p_2)p_3 \\ &\quad - p_2 - (1 - p_2)p_3 \\ &= p_1 + (1 - p_1)p_2 - p_2 \\ &\quad + (1 - p_1 - 1)(1 - p_2)p_3 \\ &= p_1 - p_1p_2 - p_1(1 - p_2)p_3 \\ &= p_1(1 - p_2) - p_1(1 - p_2)p_3 \\ &= p_1(1 - p_2)(1 - p_3) \geq 0. \end{aligned} \quad (17)$$

From equations: (16), (17) and (18), we deduce that:

$$\begin{aligned} p_{ij} &= p_i + (1 - p_i)p_j, \\ p_{ho} - p_{ij} &= p_k(1 - p_i)(1 - p_j) \geq 0, \\ \forall i \neq j \neq k, \quad \text{and } (i, j, k) &\in \{1, 2, 3\}^3 \end{aligned} \quad (18)$$

- Expression of p_{ho} as a function of $p_{ij}, \forall i \neq j$ and $(i, j) \in \{1, 2, 3\}^2$.

From equation (19) and after simplification, we can write:

$$\begin{aligned} p_{ho} &= p_k + (1 - p_k)p_{ij} \\ \forall i \neq j \neq k, \quad \text{and } (i, j, k) &\in \{1, 2, 3\}^3 \end{aligned} \quad (19)$$

Analytically, we have established that the decentralization of services is better than its centralization at one or two levels.

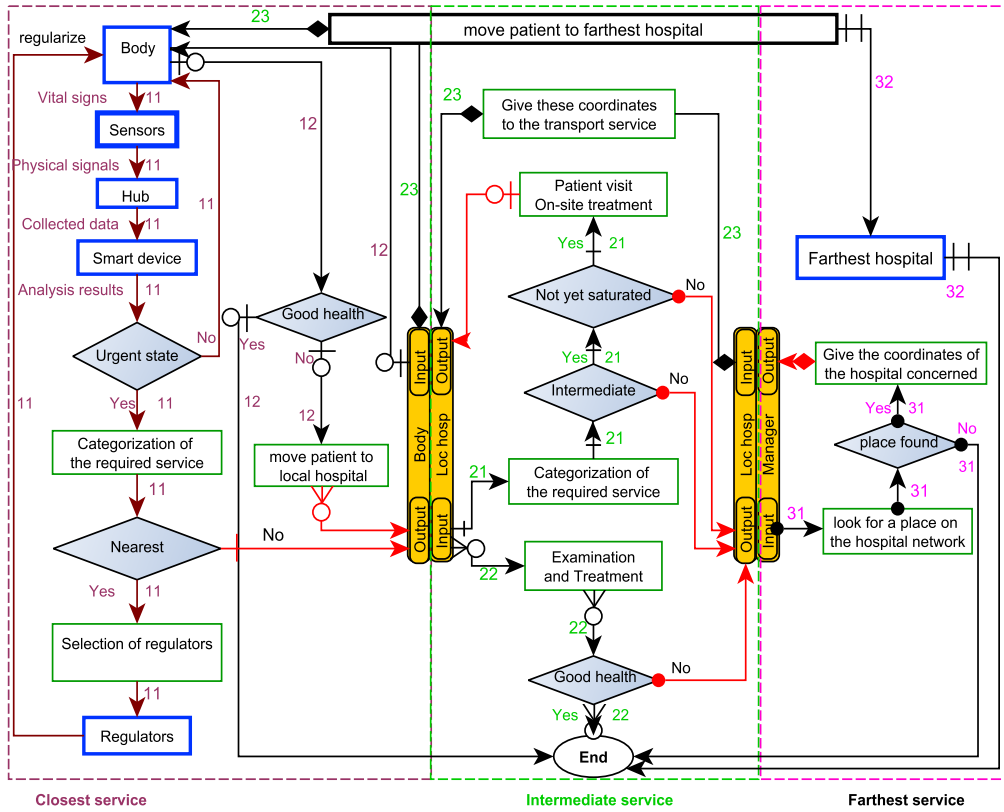


Fig. 3. Functional architecture: closest layer identified by number 1 (11: 1st time, 12: 2nd time), intermediate layer indicated by number 2 (21: 1st time, 22: 2nd time, 23: 3rd time) and farthest layer represented by number 3 (31: 1st time, 32: 2nd time).

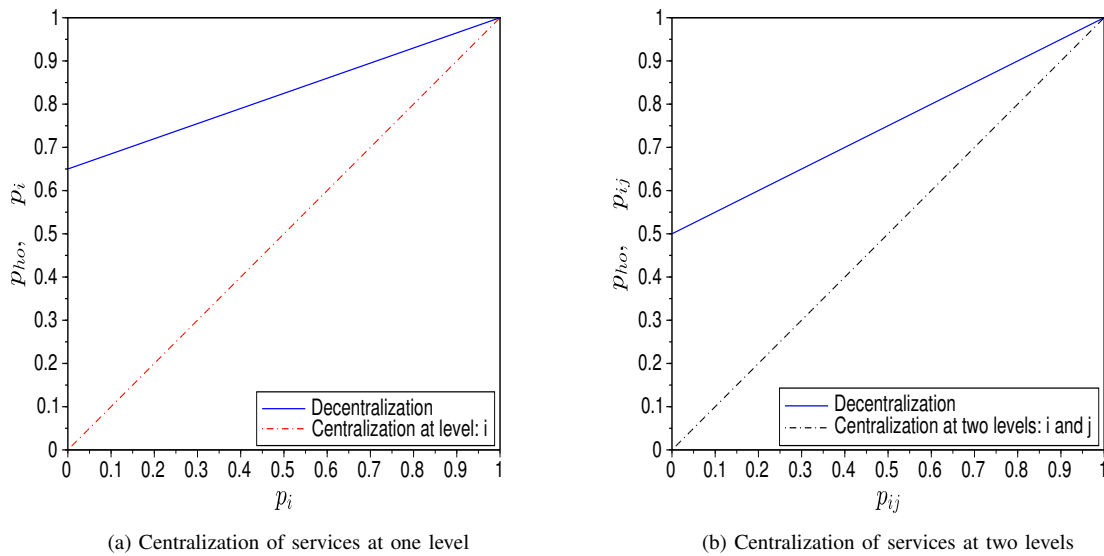


Fig. 4. Comparison between decentralization and centralization of services

V. SIMULATIONS

Currently, we graph the results, to visually show the performance of our model. This graphical representation is based

on equation (15) and (20), to make the comparison with the decentralization of services and their centralization at one level or at two levels, respectively.

The comparison between the decentralization of services

and their concentration in a single level is illustrated in sub figure 4.(a). To do this, we choose numerical values within the interval $[0, 1]$, for the probability of healing p_i at the level i , and we represent them on the x-axis. The y-axis is devoted to the enumeration of the values of p_i and the probability of healing by our model p_{ho} . In addition, to show the difference between decentralization and centralization at two levels, we draw the curves of sub figure 4.(b): on the x-axis are placed the values of the probability of healing p_{ij} for level i and j together. On the y-axis, we distribute the values of p_{ho} and p_{ij} . We can easily notice that the distribution of services through three levels is always better than their centralization at a single level or at two levels. This result is interpreted by the collaboration of three services to meet the needs of a patient, more efficiently than a single level or even two.

VI. CONCLUSION

In this work, we have designed a functional WBAN architecture that is formed by three layers named based on their locations in relation to the patient: closest, intermediate and farthest. The closest detects the vital signs through the sensors that are placed on the body. These signs are converted into physical signals, in order to transmit them to an intelligent device, which performs treatments, to categorize the state of health. In the event of a locally treatable anomaly, the regulators concerned and the adjusted values are specified. Otherwise, a rescue message will be sent to the intermediate layer, namely the local hospital, which will consult the patient on site, by using a mobile service, to carry out preliminary treatments. In case of regulation, the service stops there; in the other case, the patient will be transported to the hospital, to make the possible diagnoses and treatments. After these efforts, the patient's condition can be adjusted, as it cannot be: in the unpleasant case, the intermediate service will ask for the help from the farthest layer, namely the hospital network manager, to find an available hospital to receive the patient. Once such a hospital is found, its coordinates will be sent to the intermediate service that will take care of the transportation of the patient to the said hospital. Such an approach makes it possible to strengthen the patient's chances of recovery and also to maximize the exploitation of the hospital resources available on a network of hospitals.

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