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Consensus Multi-Health Care Systems with Optimized Quality of Measurement

Noor A. Yousif [1], Diyar J. Naji [2], Ayman Al-Khazraji [3] and Safanah M. Raafat[1]

[1] *Control and System Engineering Department, University of Technology, Iraq*
[2] *Biomedical Engineering Department, University of Technology, Iraq*
[3] *Department of Electrical and Electronics Engineering, University of Bahrain, Bahrain*

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Abstract: A health care system (HCS) has promptly progressed owing to the increasing need for accurate reactions in seriously urgent situations of health, especially for elderly people. The well-being of patients throughout the curing time as well as observing and keeping excellent measurement with reduced power consumption and cost all together forms the nature of the HCS. To tackle these objectives, a remote online observing network system has been assembled here to afford reliable correct measurements using a reduced amount of energy utilization. In this paper, the required measurements are provided by a simulated healthcare measuring device. A Quality of inference $QoInf$ function is optimized via an intelligent Brute Force algorithm in order to choose most acceptable set of sensors that will provide high accuracy but also the lowest cost. Moreover, to maintain the least power consumption within a group of monitored HCSs, a theoretical framework of consensus algorithms has been proposed. The analysis of the framework is based on algebraic graph theory. Simulation results show the effectiveness of the proposed approach. It has been noticed that the consensus application comprises the need for low power when dealing with a network of wireless sensors used for health care monitoring.

Keywords: Health care system, Brute force optimization algorithm, quality of inference, consensus algorithm, energy consumption.

1. Introduction

The wireless sensor networks are an optimum technology for monitoring in the real-time intervention of physiological parameters. It is applied to remote monitoring for medical purposes, such as monitoring of vital signs in intensive care units, monitoring patients in emergency units, monitoring chronic disease patients [1], [2], [3], [4], and monitoring elderly people at home for twenty-four hours to early detect various types of diseases.

Due to the importance of monitoring the older patients and chronic disease patients in HCS, the importance of newly developed technology has increased. In [5], four points were proposed which are activity area monitoring, physiological function, prevention of fall, and emergency assist. In [6], they are concerned with the risk of fall for the elderly patient and continuously monitoring them. The researchers in [7] introduced monitoring signal condition aware IoT enabled ECG system for continuous HCS, where two communication mechanisms had been applied using crypto primitives to ensure the privacy of the transmission. Alwan and Rao in [8] worked on an effective embedded system that works in wireless sensor networking using ZigBee, which has the ability in transmitting data in a wide range. In [9], a monitoring wearable frame system is introduced. It used ECG and SpO2 sensors. A healthcare system (non-intrusive) is designed based on a wireless sensor network (WSN) for covering a large area with a minimum battery power to back up the RF transmission. In [10], a HCS was developed depending on vibration sensors, where the vibrations of some behaviors such as falling and walking are analyzed. The designed system decides the state of the old person and sends the result to a robot. In [11], the health care system is designed to overcome the narrow capacity of computing and the need for an optimized network for the low-power W-IoT devices to manage and run the data of healthcare efficiently.

As can be noticed, a huge commercial movement has been noticed which makes extensive use of remote monitoring, medical sensors (e.g. SpO2 monitors), non-medical sensors (e.g. accelerometer), and in-situ sensors (e.g. thermal and motion detectors). The data that we can fetch from the sensors show patients' medical situations. A certain identified situation can specify the estimations we get by some sensors' measured data. A situation or (context) statement

E-mail address: 60028@uotechnology.edu.iq, bme.visit.02@uotechnology.edu.iq, aalkhazraji@uob.edu.bh, 60154@uotechnology.edu.iq

refers to a featured case as an activity, relationship, and ability. Sophisticated situations or contexts are hard to be sensed using only one sensor, thus it should be predicted from the measurements of some sensors that impacted in the neighboring [12]. The major conflict in practicing health care is the energy dissipation by sensors and their network system. Meanwhile, health care applications are widely used and increasingly spread due to the large variety and compact sensor device that assists in monitoring basic signals of the HCS [13].

The framework of optimal HCS is opposing the threat of a rapid increase in the population of old people which requires the focus of HCS on handling the wellbeing, not only the illness as well as the early recognition of sickness. Wearable systems are the most important technology that helps to transmit data continuously and are highly motivated not expensive ways. Decreasing money expenditure and cost lowering are crucial for HCS, particularly when facing a high increase in the population of the elderly. Consequently, wireless sensor networks (WSN) have been widely used in the last few years because of the low expensiveness, low power, multi-hop networks, scalability, and reliability criteria [14].

The stand-alone body sensor network involves several small wireless nodes, located at the patient's body or inside the body, which offer the functionality of sensing and processing needed by the application. Particularly, a central node collects and records the reading of the biosensors such as EEG, SpO2, EMG, ECG, blood pressure, blood flow for a while as well as dealing with the interpretation and the necessary analysis. Moreover, other sensors might be supplied or attached to the body to improve the related information like accelerometers. By adding capabilities for user I/O and the local processing of the measurements, the patient is notified at the time when his health state gets worse. Meanwhile, there are many useful topologies such as star and mesh topologies that are the best for this application.

The star topology implies a centralized architecture where the intelligence of the system is concentrated on a central node. This central node is superior to the peripheral sensors, in terms of resources such as processing, memory, and power [15] whenever simplicity, as well as long bandwidth, is required; the star topology is the best choice.

The UbiMon project [16] implements this approach where Personal Digital Assistant (PAD) is used as local processing units for collecting, analyzing, and displaying the sensor signals. A serious common problem with a medical sensor node in a network is the consumption of energy as the sensor node takes its power from a limited lifetime battery. The battery needs to be changed and replaced or recharged and sometimes this is not an option. The sensor node uses the battery's energy and monitors the surrounding environment. Energy consumption should be managed efficiently and in a good strategy so that the power consumed can be decreased to the minimum. On the other hand, the Consensus algorithm is known to be effective in managing the energy consumption of power in WSN [17].

Due to the highlighted importance of using the HCS, the interest has increased in improving its abilities and developed its performance, as in [18], where the focus was on assisting the human being by improving the aspect of health care using the technology of WSN to solve the problems of energy management. Nevertheless, the works in [13], [17], [18] didn't consider the problem of saving energy in a large network and how to minimize the power consumption, therefore we propose to use a consensus algorithm for this purpose. On the other hand, in [19], the researchers developed integrated proof-of-game- consensus algorithms for the healthcare system. Block-chain technology and consensus mechanisms have been applied to the billing system. Meanwhile, in [20], the researchers introduce the internet of medical thing device for covid-19 to collect the data related to the medical sensor then transmit them to health care centers with low power. The developed framework utilizes Kruskal's approach with cipher blockchain for minimizing routing cost.

In this paper, the minimization of the data set using Brute Force optimization to get the best quality has been combined with power reduction by the consensus algorithm. The purpose is to provide sustainable behaviour and improved transmission quality.

2. Selection of optimal set of sensors in a network system

This section presents the inference model, optimal sensors subsets, and the use of brute force to select the optimal set of sensors.

A. *Context inference model*

The Context shows the dynamically status changing to specific body status [12], [21] (e.g. sitting vs. standing or walking vs. sleeping) or medical condition (e.g. Hypotension, dyspnea, etc.) or near environmental status (e.g. CO2 level, temperature), and these are detected by the sensors that are put in the surrounding environment, like motion and thermal sensor, etc. These sensors can be used to detect and monitor every medical condition such as ECG, EMG, SPO2, and blood pressure. The number of sensors is related to the contexts needed to be monitored so increasing sensor number when needed results in increasing the contexts monitored. It is necessary to develop a strategy to transfer the context value to the health center with optimum accuracy, minimum cost, and effectiveness, as well as suggesting a proper action. In [13] a method has been developed to handle such contexts by using a precise unique design which is the QoInf. It represents the average error probability in estimating a context state, using imprecise values from the implemented sensors. Meanwhile, it is important to apply wireless sensor networking in order to ensure consistent monitoring and high accuracy in the healthcare system. It is also necessary to take into consideration the system's cost so that it can be available for all people. In addition, power management and sensor data volume reduction are necessary. Accordingly, it is required to collect a subset of sensor data that goes with minimum cost and power and with high accuracy. For this purpose, a formal approach is applied in this paper, to minimize the cost and reduce the power of an individual context in an intelligent environment. The structure of this approach makes use of event-driven data that shows each sensor (individual) is linked with a tolerance range with a clear functional model *QoInf*.

B. QoInf model

Given a set of sensors, M, Let presume that d_i is the data value of measuring sensor $m_i \in M$. Let Λ_i be the range of m_i values. Determination a context C_m value is represented by mapping function $f_{Cm}(:)$ which takes values from a subset of sensors $\delta \subseteq M$ as input and maps them into the output context Λ_{C_m} [21]

$$f_{cm} : (\delta) \prod_{m_i \in \delta} d_i \Rightarrow x : x \in \Lambda_{C_m} \tag{1}$$

The different values of the same context can be concluded with changing accuracy using different subsets of sensors. Meantime, $QoInf(\delta)$ is a function that correlates with accuracy, where $QoInf(\delta)$ denotes the average accuracy in the estimating of context C_m based on the sensors values in δ.

$$QoInf(\delta) = \frac{1 - \sum_{x \in \Lambda_{C_m}} errc(x, \{m_i \in \delta\})}{|\Lambda_{C_m}|} \tag{2}$$

where $errc(x, \{m_i \in \delta\})$ represents the probability of error when accurate measurements are taken from the subset of sensors δ, as the actual context C_m is x. Figure (1) illustrates implemented structure of the $QoInf$ function; The minimum required $QoInf$ is shown by the context modular while monitoring the application response of the surrounding condition changes the minimum $QoInf$. The optimizer context determines the optimal computation and minimum cost and of the sensor using a brute force optimization algorithm to obtain the required $QoInf$. Finally, the context estimator receives sensor data and provides the data update continuously for the context variable [12], [17].

C. Optimal subset of sensors

The essential goal of the $QoInf$ model is to decrease the energy cost related to the transmission of data while maintaining the context requirements. The following equation calculates the best subgroup of sensor which satisfies the least cost and the necessary $QoInf$ [13].

$$ti_b(i) = 1 - \frac{1}{d_i} \exp\left(\frac{-1}{\eta_i t_i}\right) \tag{3}$$

whereη_i, t_1 are sensitivity constants that differ to each context of toleration range t_i of sensor m_i, $t_{bi}(i)$ indicates the minimum of a single context $QoInf$. The error rate can be represented in equation (2) as [13]:

$$error\ rate = 1 - t_{bi}(i) = e^{\frac{-1}{t_i}} \tag{4}$$

where the assumption that $d_1 = \eta_i = 1$ is considered for simplicity. Note that always the value of $QoInf$ function is ranging between 0 and 1. Equation (5) computes the average cost for multiple sensors where (h_i) is the cost of hop function and (t_i) is the range of tolerance. The

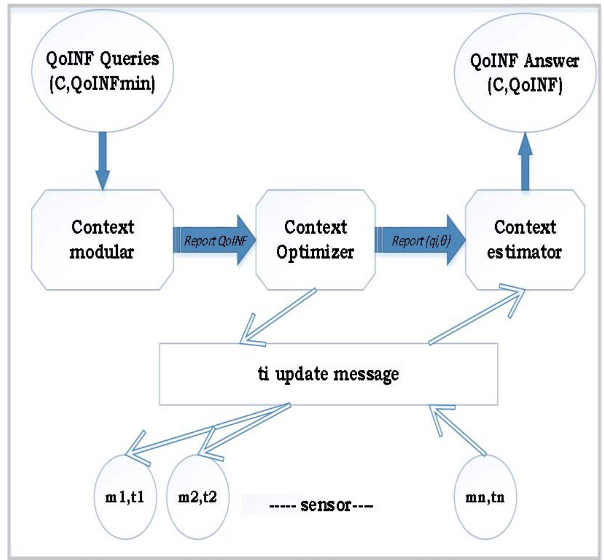

Figure 1. Structure of $QoInf$

relationship between cost and tolerance range t_i inversely proportional where an increase in t_i result in less necessity for frequent communication [22]. The optimal and the finest sensors subset and their related tolerance range can be found using an optimizing technique. The resulted accumulative cost function of the subset δ of a selection of sensor is presented as [21]

$$cost(\delta, t_\delta) = k \sum_{m_i \in \delta} \left(\frac{h_i}{t_i^2}\right) \tag{5}$$

where k is a scaling factor and the h_i is the hop count. It can be seen that h_i is the cost of hop function and t_i is the tolerated range. In this paper, we take two probabilities for the hop as 1 and 2.

Consequently, the following optimization problem is formulated to find and discover both optimal subgroups of sensor and related tolerance range: Minimize the cost function:

$$\sum_{m_i \in \delta} \frac{h_i}{t_i^2} \tag{6}$$

Subject to the constraints

$$\sum_{l=1}^{L} \lambda_l \left[1 - \prod_{m_i \in \delta} \left(\frac{1}{d_{il}} e^{\frac{-1}{\eta_{il} t_i}}\right) - QoInf_{min}^l\right]$$

The optimization approach using the Lagrangian method will be expressed as .

$$\sum_{m_i \in \delta} \frac{h_i}{t_i^2} + \sum_{l=1}^{L} \lambda_l \left[1 - \prod_{m_i \in \delta} \left(\frac{1}{d_{il}} e^{\frac{-1}{\eta_{il} t_i}}\right) - QoInf_{min}^l\right] \tag{7}$$

whereh_i is the hop count, the track relating between the sensor m_i and the sink, λ_l is the Lagrangian multiplier for situation l, δ is a set of sensors, $QoInf_{min}^l$ represent the minimum for the $QoInf$ for situation l.

D. Optimal set of sensor selection based on brute force

One of the important intelligent algorithms is the Brute force approach shown below, which can be used to fulfill the compatibility among appropriate cost and the required $QoInf$ using all the available sets of sensors in a specific context. The method is described by the flow chart shown in Figure (2). It can be seen that the Brute force returns the optimum sensor subset δ and the lowest cost.
In the beginning, the minimum cost and minimum required $QoInf$ must be identified for every available sensor of a specific context, then return to a minimum cost and optimal subset if the minimum cost and the required $QoInf$ is achieved by the first sensor calculations, otherwise proceed with the next available sensor to find which one can accomplish the minimum cost and required $QoInf$. The same procedure is applied for every available sensor, till the optimum sensors subset and minimum cost is obtained [13].

Algorithm 1 Procedure Brute Force Multi fusion

Input : Set M, $QoInf^{l}_{min}, \forall l = (1, \ldots.., L)$ [20]
Output : Optimal sensor subset δ with minimum cost

Initialize empty set of sensor:
$\delta = \emptyset$; $\widehat{cost}\ (\delta) = 0$; $MinCost\,(l) = \infty$
Find the power set of S; assume $\delta \subseteq p\ (M)$
for $(i = 1; i < |p\,(M)|\,; i++)$ **do**
  for $(l = 1; l <= L; l++)$ **do**
    Compute the tolerance range t_i
    if $QoInf^{l}_{min}\,(p\,(M)) \geq QoInf^{l}_{min}$, $\forall l$ *and* t_i **then**
      $\delta = p\,(M)$
      Compute updated cost; $\widehat{cost}\,(\delta)$ for $QoInf^{l}_{min}$
      if $\left(\widehat{cost}\,(\delta) - MinCost\,(l)\right) < 0$ **then**
        $MinCost\,(l) = \widehat{cost}\,(\delta)$
    else Break; move to the next
      Compute updated cost; $\widehat{cost}\,(\delta)$ for $QoInf^{l}_{min}$
  end l
end i
Return $\{\delta, minimum\ \widehat{cost}\,(\delta)\}$

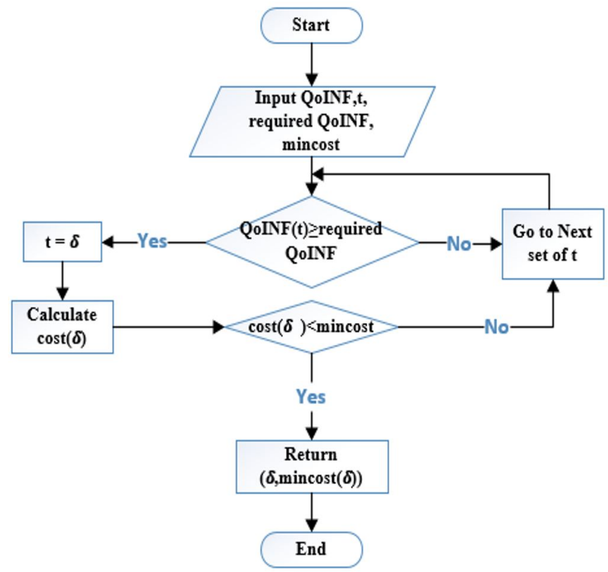

Figure 2. A Flowchart for Brute force algorithm.

3. Communication in wireless health care network system (WHCNS)

Typical sensors in a HCS node consist of four components: sensing element, processing, a transceiver, and the power units. Furthermore, an additional component such as location-finding systems can be used as well. Usually, WHCNS nodes are provided with sensors that contain the ability to gather the data to the sink and end-user. The sink interconnects to another node via the internet or satellite [23], [24].

A. Communication and applied topology for WHCNS

Nodes are generally arranged to form the star topology (every node is attached to the main hop named the sink node or the multi-hop mesh networks). In the star topology, each node is openly linked to the central hop. An important benefit of using the star topology is that as long as the central hop is working and active the node that fails will not affect the network, that's why it is useful and efficient in the HCSs. Due to centralized control in the star topology, the status of every node is informed only by the sink node (center). When one of the nodes needs to transmit its data the other nodes will be inactive. One of the disadvantages of the star topology is that the size of the network is increasing, which means increasing the power consumption. Furthermore, the increased distance between nodes causes higher power radio. On the other hand, with a mesh multi-hop network, every node is attached to the closest neighbors' node, where each data is transmitted to the server using a routing or flooding algorithm [25].
The mesh topology is more robust and resistant to node failure as compared to the star topology because the nodes are connected to each other via a dedicated link that enables self-healing capability, so when a path is fallen, the data is rerouted to a different one. The drawback of mesh topology is the relatively high cost compared to other network topologies and the difficulty of maintenance and configuration. Since only the hop node knows the state of the other nodes, the mesh is centralized control. The star and mesh topologies are shown in figure (3). The communication standard between the sensor node and a variety of networks can be developed for low power consumption.

4. Consensus of WHCNS

A common problem with WANs is that the lifetime of the network sensor will be reduced because of the enormous density and the large size of the WANs. The improvement of WANs is difficult because the energy consumed in the whole sensors of the network must be reduced to extend the lifetime of the network. So, the sustainable design of

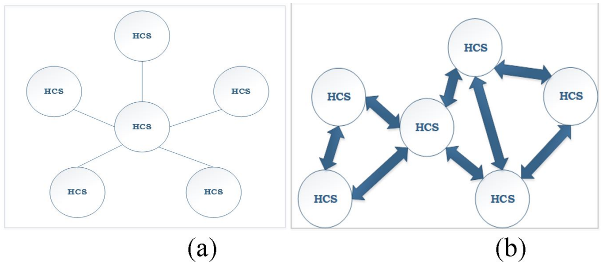

Figure 3. Star mesh topologies.

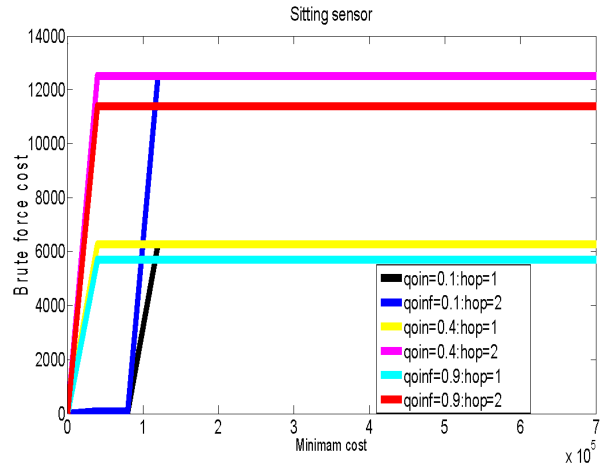

Figure 4. the relation result between the minimized cost and the cost δ using the algorithm of brute force for the sensor of running.

the WHCNS is considered the most important problem. Furthermore, the energy compelled the sensor to work automatically for an extended period, besides the change in the price of the battery is critical for the unfavourable environment [26].

Several algorithms have been found to minimize the energy consumption in WANs. The consensus algorithms are considered low complexity, repeated, and conventional algorithms. The consumed energy is linked to the necessary time to calculate the consensus value of starting up energy. The time required for convergence is a crucial factor to evaluate the implementation of a consensus algorithm [27]. The required value of the consensus algorithm can be achieved by using the mathematical representation in graph theory, as will be described next. The theoretic progress of the consensus algorithm in both continuous and discrete-time of the network has been checked [28], [29]:

$$\alpha = N^{-1} \sum_{i=1}^{N} X_{ki}(0) \tag{8}$$

where X_{ki} represents every node state and α represents the acceleration factor. At time = 0, every node has a native variable $X_{ki}(0)$, while the aim of the above equation is for every node in the network to calculate the state of its neighbour and update its variable state as stated by the algorithm of consensus.

In a discrete-time domain, the consensus algorithm for a network system can be calculated as follows:

$$X_{ki}(k+1) = X_{ki}(k) + \epsilon \sum_{j \in N} a_{ij}(X_{kj}(k) - X_{ki}(k)) \tag{9}$$

where: ϵ is a mixing factor, k is the time instant, a_{ij} of the adjacency matrix A specifies if the node i and the node j are neighbors; $a_{ij} = 1$ for neighbouring nodes, and it equals 0 in the opposite case [30]. The node's state is updated depending on the neighbour's collected state, all nodes have to agree on the same parameter of $\epsilon \in (\frac{\beta}{\Delta}$ where in the network Δ is the number of a degree out depending on the graph theory connection and β is a real variable number that ranges between $(0-1)$ [31], [32].

5. Simulation and discussion

According to the simulated data from , there are contexts of three sensors like walking, sitting, and running with a corresponding tolerance value t_i are prepared using the MATLAB program. So the values of the corresponding set of the context of the three sensors have been obtained. In Eq.(3), the relation between both $QoInf(i)$ and t_i is an exponential decay, so, one minus indicates that $QoInf$ value is a percentage between $(0 and 1)$. The aim is to apply the algorithm of brute force and analyse its effects to choose the excellent set of sensors that satisfy minimum cost and best accuracy. Furthermore, the application of the consensus algorithm reduces energy overhead in the WHCNS. Detailed descriptions of the results are presented as follows: Brute force Optimization for various motion sensors As mentioned in Section (2.3), the brute force algorithm is applied for three sensors of motion which are (running, sitting, and walking) context. The prescribed $QoInf$ is $[0.1, 0.4, 0.9]$, depending on the values of the contexts $QoInf$. All the possible sets of sensors will be tested by brute force, then for every set, it will be determined whether it satisfies the required $QoInf$ for each context. Figure (4) shows the context of sitting, Figure (5) shows the context of walking, and Figure (6) shows the context of running. It can be noticed that by using the Brute force optimization algorithm, an increase in the required QoInf results in a decrease in cost based on the contexts QoINF values. Brute force will iterate all possible sets of sensors then determine for each whether it satisfies the required $QoInf$ for all contexts. If so then determine the cost of using that subset. Accordingly, the sensor with $QoInf = 0.9$ and hop=1 will be selected for sitting context, the sensor with $QoInf = 0.9$ and hop=1 will be selected for walking context, and $QoInf = 0.9$ and $hop = 1$ will be selected for running context because they satisfy the lowest cost.

A. WHCNS consensus performance in star topology

Suppose there are N nodes of WHCNS placed in one area connected using star topology, the consensus information of every node is sent to a central node using a specific topology named direct; in Figure (7) a network of 18 nodes using star connection is shown. In WHCNS every node has

Figure 5. the relation result between the minimized cost and the cost δ using the algorithm of brute force for the sensor of walking.

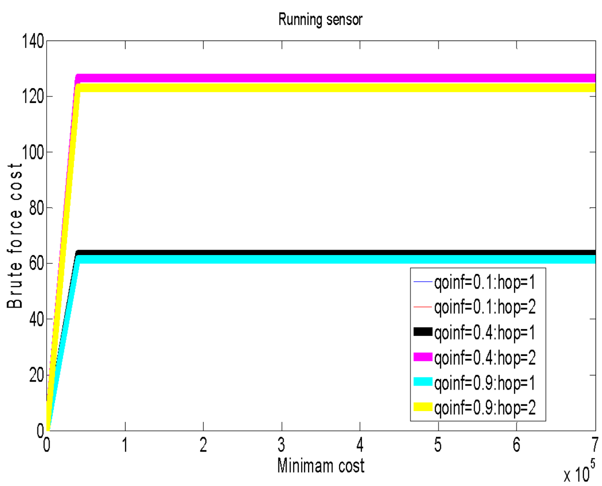

Figure 6. the relation result between the minimized cost and the cost δ using the algorithm of brute force for the sensor of running.

an initial state Xi where i represents the node's number. Figure (8) demonstrates the initial states of 18 nodes. The information of each node is updated depending on the state of the input, every update represents a new iteration The major target of the consensus algorithm is reducing the WHCNS iterations to the minimum value; this reduction causes more energy saving in WHCNS. As a result, the energy is reduced as much as possible, increased accuracy, and reduced the data cost sent to the health manager. By using MATLAB the consensus algorithm performance has been applied. As explained earlier, the states of an 18 node network are updated at every iteration to meet the consensus value. Figure (9) shows the consensus application where every status equals the value of consensus. Every node reaches the value of consensus based on the used consensus algorithm. Many iterations later, WSN requires more power. The number of repetitions is influenced by the ϵ which is commonly selected as a constant number depending on $\epsilon = \frac{\beta}{\Delta}$. An example of 18 nodes with $\beta = 0.8$ requires 5

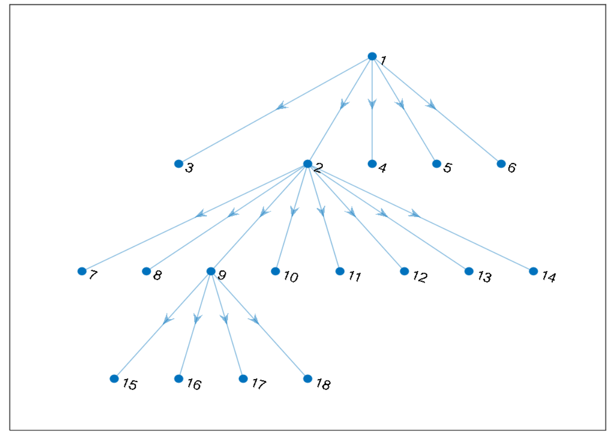

Figure 7. Eighteen health- care- node systems in star connection.

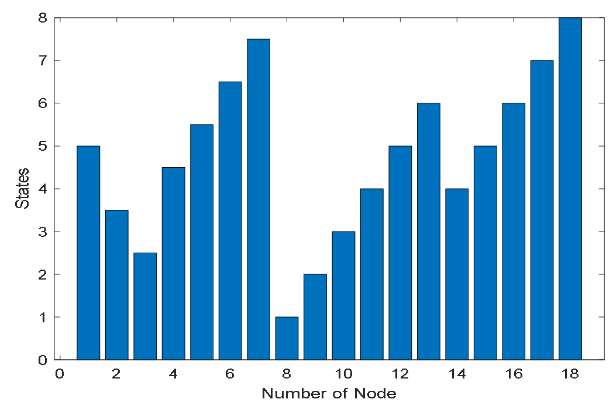

Figure 8. Initial states of eighteen health- care- node systems.

iterations to reach the value of consensus as shown in Figure (10), which means a relatively low power consumption spent in WSN.

B. WHCNS consensus algorithm performance with mesh topology

A network of 18 nodes using mesh connection is shown in Figure (11), while Figure (12) shows that every sensor

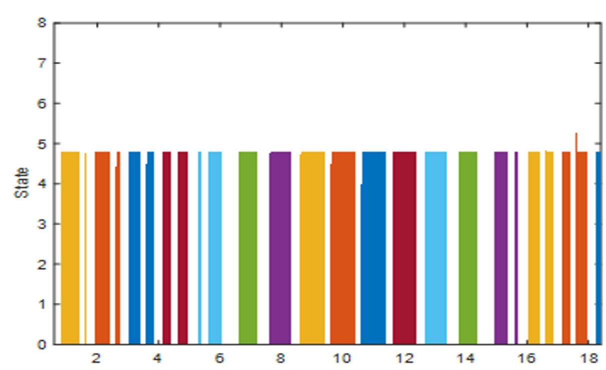

Figure 9. States of eighteen HCSs in consensus.

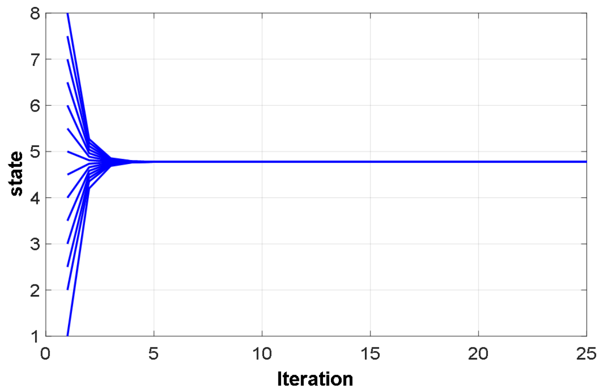

Figure 10. Eighteen HCSs reached the consensus value, at $\beta = 0.8$.

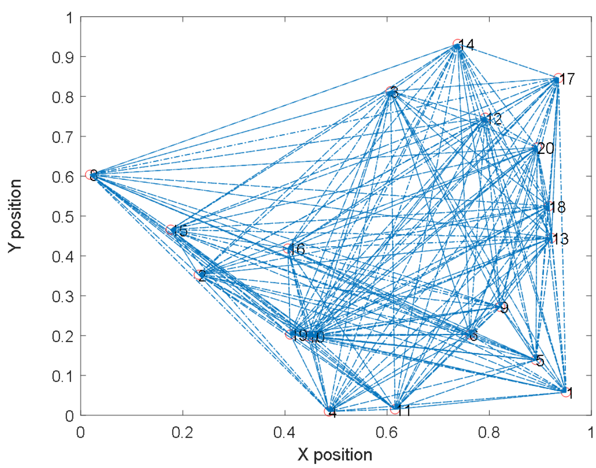

Figure 11. Eighteen HCSs in mesh connection.

has an initial state xi where the i symbolizes nodes number. The consensus algorithm achieves the reaching task based on mesh topology based on the (18) nodes that are uniformly arranged in the unit area. At first, each node gathers its neighbors' states then updates its state according to the information that has been gathered to reach the new steady state of the consensus value. In a mesh network every sensor is formed by a unidirectional graph theory G_n (V_n, E_n), where the vertices $V_n = [1 \dashrightarrow N]$ and the edges $E_n \subseteq V_n \times V_n$, N represents the number of nodes.

Figure (13) demonstrates the result for applying the algorithm of consensus, where every state reaches a consensus value. The (18) nodes that are connected with the mesh network have $\beta = 0.8$ require 6 iterations to reach the consensus value, as can be seen in Figure (14). By comparing the result of applying the algorithm of consensuses to both mesh and star topologies, the consumption of power in the star topology is relatively less than the mesh topology due to multiple intermediate hops, since every hop that passes through the node consumes power In addition, the power saving is applied to every node excluding the central one (central node) in the star topology, while in the mesh topology the power saving is applied to every node.

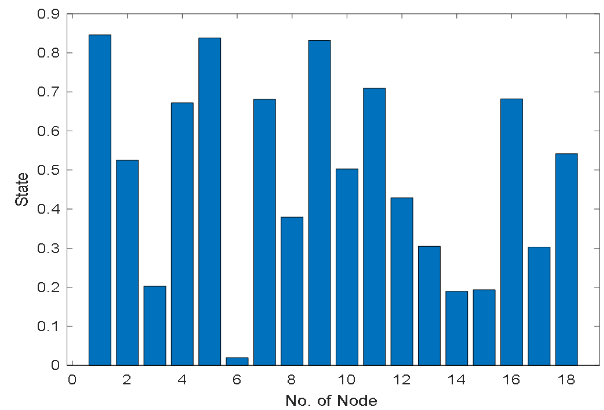

Figure 12. Initial states of eighteen HCSs.

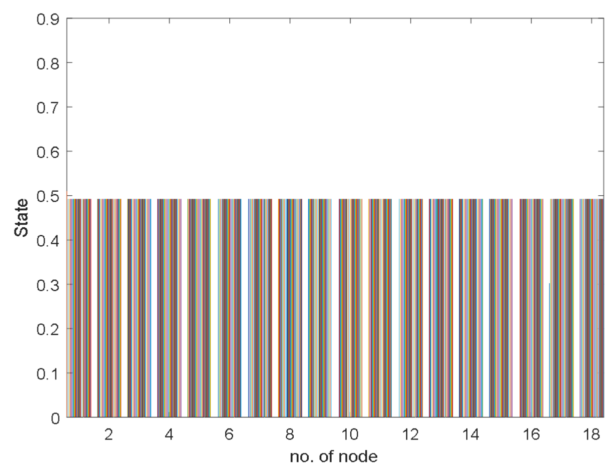

Figure 13. States of eighteen HCSs in consensus.

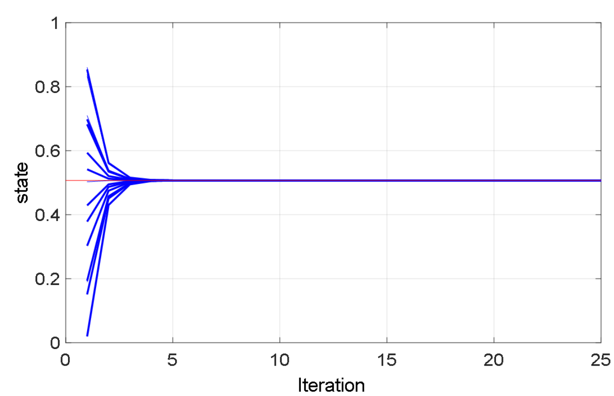

Figure 14. Eighteen HCSs reached the consensus value, at $\beta = 0.8$.

6. Conclusions

In this paper, a sustainable health care system for elderly people has been developed. It starts by selecting the best set of measurements by optimizing the quality of the inference cost function, based on the measurements of three sensors (sitting, walking, and running). Brute force optimization has been used to find the optimum subset of the sensors. The optimization issue is solved by introducing an algorithm of multi-contexts that deals with the computational cost of communication and the accuracy problem. This algorithm can considerably minimize the computational cost with high accuracy because it selects the sensor with the higher quality of the interface. The next stage of the work is to manage the consumption of energy in the wireless HCS. The communication topology is built via using either star or mesh connection nodes. Accordingly, a consensus algorithm is performed to considerably reduce energy consumption in a WSN of HCS. It has been noticed that the consensus application comprises the need for low power when dealing with a network of wireless sensors used for health care monitoring. Practical development of a health care system using a network of wireless sensors will be considered for future work.

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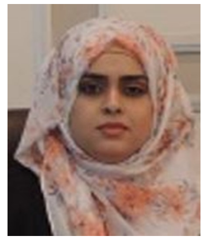
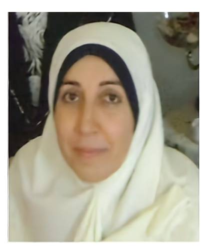
Noor Ayad Yousif Noor A. Yousif (BEng and MSc Eng in Computer Engineering), is a faculty member at Control and System Engineering Dept., University of Technology-Baghdad. Her main research interest includes signal processing, artificial intelligence, IoT, and optimization.



Diyar Jalal Naji Diyar J. Naji (BEng, MSc in mechatronics engineering), is a faculty member at Biomedical Engineering Depart., University of Technology-Baghdad. Her main research interest includes healthcare systems, artificial intelligence, control systems, modelling, and optimization.

Ayman Al-Khazraji Ayman Al-Khazraji (BEng, MSc Eng, PhD in Computer and Electrical Engineering), is an assistant professor at the Electrical and Electronics Engineering Dept., University of Bahrain. Dr. Al-Khazraji's experience in academia and industry spans over two decades. He is the recipient of IFAC best paper award (EAAI-2014). He also serves as a regular reviewer, session chair, TPC member and organizer of numerous reputed ISI indexed journals, IEEE conferences, and symposiums (MENACOMM'19, 3ICT'19-21, IEEE CCECE'20, MobiSPC'20, SCS'20-21, DASA'20-21, DATA'20-21, SRC'20-21). His research interests include, but not limited to, AI, smart cities, robotics, control systems, engineering education, monitoring and fault detection, optimization, and IoT.



Safanah M. Raafat (BEng, MSc Eng, PhD in Control and System Engineering), is a Professor at Control and System Engineering Department at the University of Technology-Baghdad. She is a Senior IEEE member and a member of IEEE Control Systems Society. Her main research interests include system identification and estimation, optimization and optimal control, robust control and robotics.