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An Energy-Efficient Mobile Agent-Based Data Aggregation Scheme for Wireless Body Area Networks

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Abstract: Due to the advancement in wireless technology and miniaturization, Wireless Body Area Networks (WBANs) have gained enormous popularity, having various applications, especially in the healthcare sector. WBANs are intrinsically resource-constrained; therefore, they have specific design and development requirements. One such highly desirable requirement is an energy-efficient and reliable Data Aggregation (DA) mechanism for WBANs. The efficient and reliable DA may ultimately push the network to operate without much human intervention and further extend the network lifetime. The conventional client-server DA paradigm becomes unsuitable and inefficient for WBANs when a large amount of data is generated in the network. Similarly, in most of the healthcare applications (patient's critical conditions), it is highly important and required to send data as soon as possible; therefore, reliable data aggregation in WBANs is of great concern. To tackle the shortcomings of the client-server DA paradigm, the Mobile Agent-Based mechanism proved to be a more workable solution. In a Mobile Agent-Based mechanism, a task-specific mobile agent (code) traverses to the intended sources to gather data. These mobile agents travel on a predefined path called itinerary; however, planning a suitable and reliable itinerary for a mobile agent is also a challenging issue in WBANs. This paper presents a new Mobile Agent-Based DA scheme for WBANs, which is energy-efficient and reliable. Firstly, in the proposed scheme, the network is divided into clusters, and cluster-heads are selected. Secondly, a mobile agent is generated from the base station to collect the required data from cluster heads. In the case, if any fault occurs in the existing itinerary, an alternate itinerary is planned in real-time without compromising the network performance. In our simulation-based validation, we have found that the proposed system delivers significantly improved fault-tolerance and reliability with energy-efficiency and extended network lifetime in WBANs.

Keywords: WBANs; mobile-agent; data aggregation; reliability

1 Introduction

The rapid growth of WBAN technology has enabled the fast and efficient acquisition and exchange of huge amounts of data in specialized fields. WBAN is a specialized network intended to connect various bio-sensor nodes located on or inside the human body. This network has a variety of tremendous applications; however, the healthcare applications of WBAN are very prominent. A WBAN provides long-term health-care monitoring of a patient without any interruption of normal daily life activities. This technology is a fast and efficient way to diagnose the patient and, at the same time, to consult the doctor or other medical staff for any required action to be taken [1]. One of the key features of WBAN is collaborative information processing to reduce data transmission to Base Station (BS) commonly known as Data Aggregation (DA). DA is the core requirement in any applications of WBAN. There are two basic types of DA techniques: clustering-based and mobile agent-based data aggregation. Both these techniques are now the noteworthy research fields that emphasize the management and preservation of the network to increase energy-efficiency and reliability of the network [2,3]. However, due to the unique nature and dynamics of WBANs, the link connectivity and data communication are usually affected. Due to which the critical data packets are lost, and it is a known fact that in WBAN, on-time, reliable and accurate data must be conveyed to the Medical Server (MS) [4]. The reliability of WBAN is directly correlated to the effective DA techniques. In reliable DA the ratio of forwarding of the critical data from bio-sensors nodes to BS is maximized. The efficient real-time DA ensures to send of critical data of the healthcare application to the MS for real-time analysis and action [5]. The importance of DA techniques in WBANs are:

- ♣ The efficient DA technique reduces the ratio of traffic; consequently, energy-efficiency is improved.
- ♣ Efficient DA supports to improve robustness in the WBANs.
- ♣ Efficient DA techniques support to minimize the ratio of redundant data packets in the Network

1.1 Motivation

Over the time, various schemes and techniques have been proposed for efficient DA in WBANs. The most common lies in the categories of cluster-based and mobile agent-based schemes. In WBAN, the bio-sensors related to a single body are brought together into a cluster. In collaborative-WBANs, data are aggregated and considered from multiple bodies. Thus collaborative-WBANs proposed a platform for efficient aggregated data exchange [6]. The DA technique minimized the exceeded data transfer in the network. Efficient DA by using a clustering approach enhanced the scalability and fault-tolerance of WBANs. The Mobile Agent-Based DA approach increases the accuracy level of data communication in WBAN. However, from the critical analysis of the related work, we concluded that not a single work considered both techniques; clustering for path/itinerary planning and mobile-agent-based technique for efficient DA in WBANs. Though some of the proposed work addressed DA, using clustering or Mobile Agent-Based DA. Still, there exist issues, and the widespread benefits of these techniques are not achieved. Therefore, we have been motivated to solve the issue of efficient DA in WBANs. DA in IoT enables WBANs can also be addressed using a similar technique.

1.2 Research Rationale

In WBANs, bio-sensor nodes regularly generate vital signs. These vital signs are further communicated to the BS regularly. The exceeded data caused reducing the throughput and reliability of the network. Thus DA approach is used for efficient data gathering. The bio-sensors nodes happen in the path towards the BS do data fusion. The accumulated data is transmitted to the BS; thus, latency inside the network is minimized. However, the DA methods sometimes reduced the accuracy level of the communicated data. Depending on the DA function, sometimes, the original data has not recuperated at the BS. Therefore, information accuracy may be lost. Therefore, a trade-off is required between DA techniques and desirable data accuracy. Thus, we proposed an energy-efficient and reliable Mobile Agent-based DA (MADA) scheme for WBAN. The novelty of the MADA scheme is a hybrid scheme in which both approaches are used in a single scheme, Clustering is used for itinerary planning while the mobile-agent approach is used for data aggregation in WBANs. This is the main contribution and worth of the research work. The MADA scheme aims to increase energy-efficiency and reliability inside the network and to reduce the end-to-end delay.

1.3 Research Contributions

To minimize excessive data forwarding from nodes to MS, we proposed a mobile agent-based DA scheme. The scheme is highly convenient in WBANs domain ensuring reliable connectivity. Additionally, the proposed scheme provides efficient DA services to the WBANs in term of packets delivery ratio and delay in life-threatening emergency applications. The main contributions of this work are given as follows:

- ♣ We ensured efficient reliable communication in WBAN to manages data forwarding among bio-sensors nodes, Gateway (GW) and MS.
- ♣ We maximized the service delivery ratio through efficient scheduling and collecting the desired critical data, which increase network throughput.
- ♣ We proposed itinerary planning for efficient DA of critical data, which minimizes the average end-to-end delay inside the network. furthermore, in the cause of fault in the existing itinerary, alternate itinerary planning is proposed to increase fault-tolerance inside the network.

The rest of the paper is organized as follows. In section 2, we briefly review the most relevant schemes related to the research problem mention above, particularly in the domain of WBAN. In section 3, the proposed scheme is demonstrated for the WBAN scenario. In section 4, the proposed scheme performance results are presented. And lastly, in section 5, the conclusion and future trends are given.

2 Literature Survey

In this section, the widely used and cited DA schemes in WBANs are critically reviewed. The two well-known classes of approaches for DA in WBAN are *cluster-based* and *mobile agent-based* DA schemes [7].

2.1 Clustered-Based Data Aggregation Approaches

In Culpepper et al. [8], proposed a Hybrid Indirect Transmission (HIT) DA scheme. The proposed scheme is based on a hybrid structure. It contains one or more clusters, where each cluster has the capability to perform multi-step transmissions. The proposed work has increase energy-efficiency and throughput because of using parallel processing between clusters during communication. However, the network delay is minimized due to the restricted traffic. Nonetheless, HIT does not provide any remedy to the Packet Delivery Ratio (PDR), a key fault-management metric.

Any-Body [9] protocol is proposed by T. Watteyne et al. for DA in which a self-organizing cluster-based approach is used which minimized the direct traffic from the bio-sensor nodes to the BS. Any-Body protocol practices a famous version of the LEACH protocol [10]. The idea is to choose the cluster head (CH) after a definite time to balance energy consumption. Thus data is gathered by the CH and then communicated to the BS. Any-Body protocol consists of five steps that are: discovering neighbors, calculate the density, CH selection, and routing path formation. Any-Body protocol increases energy-efficiency and throughput. However, the end-to-end delay and node mobility is not considered, which are the most important related aspects to DA [11].

Sasirekha et al. in [12] proposed a cluster chain-based mobile agent routing algorithm named (CCMAR) for DA in WSN. This algorithm takes advantage of LEACH and power-efficient data gathering in sensor information systems named as (PEGASIS). The proposed algorithm is simulated in NS-2 and compared the simulation results with the Any-Body protocol as mentioned above. The simulation result shows that the proposed algorithm gives improved results as compared to famous DA protocols.

Reddy et al. [6] proposed a procedure for the aggregation of delay-sensitive communication known as (DAP-DS) in WBAN. In the proposed work, the data related to many WBAN are collected. The collected data are associated with different bio-sensor nodes. In DAP-DS, the focus is on delay-sensitive messages in this approach. The output results showed that the proposed scheme is more robust and scalable. However, the fault-tolerance parameters are not addressed in the proposed scheme.

2.2 Agent-Based Data Aggregation Approaches

Liu et al. [13] proposed a scheme for itinerary planning using multi-agent by building a spanning tree in WSN. Furthermore, an algorithm named Disjoint Multi-Agent Itinerary Planning (DMAIP) is presented in the proposed work. This algorithm makes a graph of the network topology, and for increase weight, a graph using a spanning tree is constructed. The graph's path has passed through the spanning tree for itinerary planning to find disconnected nodes inside the network's subtrees. Similarly, Aloui et al. [14] proposed an approach using a multi-mobile agent for itinerary planning. MIP (Multiple-agent Itinerary Planning) is an interesting approach used to reduce energy consumption in WBAN. MIP approach causes emergency data distribution among agents de-stabilizing. SIP (Single-agent Itinerary Planning) is the simple approach used for itinerary planning. In the proposed work MIP approach has been used for itinerary planning in cause where geographical distance is the important factor. Thus, a new GIGM-MIP approach that consider geographic information is used for itinerary planning. That sends less amount of data packets which are generated by each bio-sensor node so, the energy consumption is minimized significantly.

Aiello et al. [15] proposed a scheme based on the mobile agent to monitor human activates in real-time WBAN. Mobile-agent is a JAVA code for human activity recognition as well as DA in WBAN. The proposed scheme contains two bio-sensors and a coordinator node. On bio-sensor, MAPS-based agents are integrated that performed sensing of the human actions and DA. The specified agent at that moment transmits the aggregated data to the coordinator node. Moreover, the experimental results of the proposed scheme demonstrate accurate activity recognition. The proposed scheme is an efficient technique for activity recognition using feature aggregation. However, the MAPS-based agent component has stringent requirements, i.e., sensing rate, communication latency of data, and compact computation.

Fissaoui et al. [16] proposed an Energy-Efficient and Fault-tolerant Algorithm for data aggregation in WSN known as (EFTA). In EFTA, a Mobile Agent (MA) based data aggregation model has been presented. MA-based data aggregation is an alternative to the traditional client-server paradigm. MA travels across to all sensor nodes (SNs) and gathers the data from them. In this algorithm, before the migration of the MA itinerary is planned. If in the existing itinerary arise failure, then EFTA assumed another itinerary for MA migration. The proposed algorithm also clustering method for grouping the sensors nodes. Using this approach, the network lifetime is improved, and the execution time becomes less than previously proposed systems. However, the EFTA algorithm ignores the fault-tolerance challenges; thus, the intended network is still prone to failure [17].

3 The Proposed MADA Scheme for WBANs

In WBAN the generated data are heterogeneous in nature. The distribution of bio-sensors is also not uniform. The research study shows that DA using a cooperative cluster-based approaches have significant impacts on the efficiency and reliability of data gathering and communication in WBANs [18,19]. In the clustering approach, the network is distributed into sub logical sets know as clusters. The primary purpose of the formation of clusters is to shrink the direct communication from source nodes to BS. In the cluster-based approach, each cluster has a Cluster Head (CH), which is selected based on definite criteria. CH provides the backbone to data gathering and communication in the network [20–23].

The main motivation behind our proposed MADA (Mobile Agent-based Data Aggregation) scheme is real-time data aggregation. In the proposed scheme, the idea of Mobile Agents (MA) is used to collect the data instead of the direct client-server paradigm. MA is a special type of software entity that migrates among CHs in WBAN to collect the sensed data from different bio-sensors [24]. For this purpose, the WBANs are divided into a cluster, and one body is considered as a cluster. After clustering, a CH is elected for each cluster. CH's collected data from bio-sensors and send them through MA through a gateway to the MS. The mobility pattern of group-based WBANs disrupts the link quality between WBAN nodes and AP/Gateway.

Furthermore, the reliability of data also degrades in WBAN [25]. The proposed scheme works inefficiently to collect the data with fewer resources of WBAN and provide high reliability to the data associated with critical emergencies, for example in healthcare applications. In the proposed scheme, an itinerary is planned before agent migration. The proposed scheme adopts the clustering method for DA in WBANs. The mobile agent moves through all CH and collects data from CHs in WBANs. If a fault occurs in the itinerary, an alternate itinerary will be constructed to ensure fault-tolerance in the network. This approach consumes less re-source of the resource constrain WBAN. Furthermore, using this novel concept ensures efficient real-time data gathering in WBANs healthcare applications [26,27].

3.1 System Model of Mobile Agent-Based Real-Time Data Aggregation (MADA)

In the proposed system model, we consider WBAN-based healthcare in which the patients are being monitored in the remote hospital environment. The network model consists of eight bio-sensor nodes on a single body; mostly on-body bio-sensors are positioned on the human body. For a broad view, three bodies are considered, and each has eight bio-sensors. Each is fitted on their specified location on the entity body in a 30×30 meter square feet area. There is a medical server (MS), accessed by a trusted entity, and Sensor Nodes (SNs) [28]. Bio-sensors and the gateway node have the same transmission range. But in terms of power and computation capability, the controller node or gateway is more powerful than bio-sensors [29]. The network model is shown in Fig. 1, demonstrated a CH in each cluster in WBANs. The CH is responsible for collaborating the aggregated information to the gateway and then further to the MS for the entity body's critical decisions. CH's collect all the necessary information about their associated bio-sensors before any communication. After that data aggregation is performed at gateway node. Such as localization and positioning information using the techniques in [30–32]. There are three main participants in the proposed scheme in WBAN. The bio-sensor nodes, the aggregator nodes, and the medical server.

3.1.1 Sensing Nodes (SNs)

Set of sensing nodes SN= (S1, S2,...,S8), which sense the vital sign from the human body such as ECG sensor, EMG sensor, and motion sensor. The sensed information is further reported to the aggregator node and then to the medical server.

3.1.2 Aggregator Nodes (AGs)

Aggregator node is connected to both MS and SNs, collected vital signs from SNs, and communicating them to the MS through CHs as shown in Fig. 1. DA operation is performed on the received vital sign data in the AG node. The healthcare data of the patient are reported to the MS for further essential healthcare provision. In MS, privacy preservation is checked. We assumed the trust-based privacy strategy according to our previous work [33].

3.1.3 Medical Server (MS)

MS is a remote medical healthcare monitoring entity where the medical decision has been carried out. MA is also initiated from the MS entity, which travels through all CHs in a predefined itinerary path [34,35].

The operations of the proposed scheme are as: First, the bio-sensors related to each body are considered as a group or cluster. For each cluster, a CH is elected according to standard LEACH protocols with little modification of the requirement of WBANs. Itinerary planning between different CHs is established by using a minimum spanning tree (MST) [19]. And then, MA migration is performed, which accomplishes data collection from all CHs. The MA is initiated from a medical server; the medical server may send multiple MAs in parallel or at a different time for data collection in WBANs [4]. Further details of the scheme are given in the below sections.

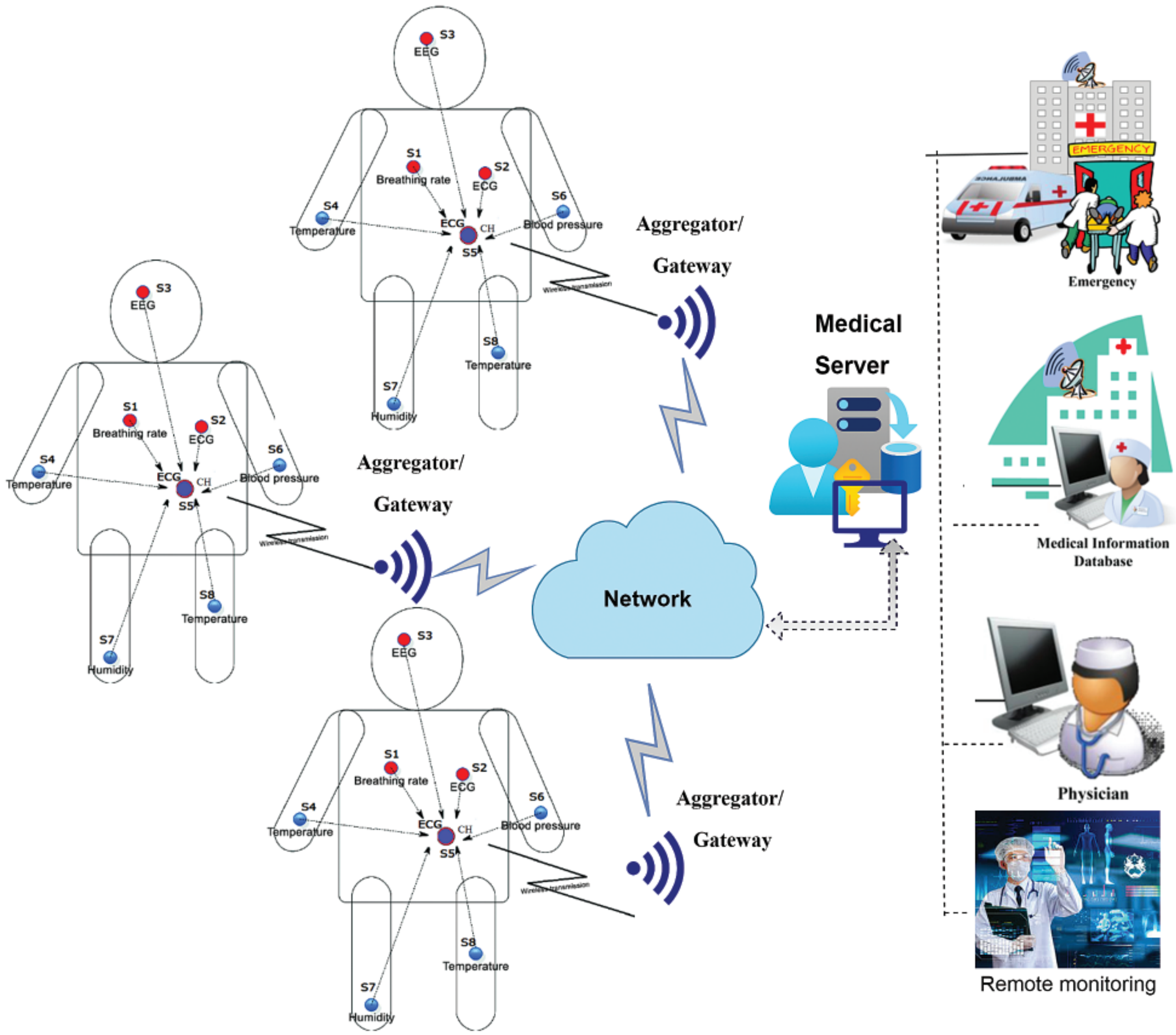

Figure 1: Network model of real-time data aggregation in WBAN

The proposed model consists of three entity-bodies, as shown in Fig. 2. Each body consists of eight bio-sensors and a CH. CH is further connected through the gateway to the MS. The sensed data from each separated bio-sensors are aggregated and then further routed to the medical server or sink to diagnose and analyse. MA is generated and travel in a specific itinerary visit all CHs whenever real-time data is needed for diagnosis purposes. Efficient DA and data dissemination are very important in WBANs. The following Tab. 1 Names and Notations used in MADA of the proposed scheme's variables. In the next section, the comprehensive steps of the proposed scheme are given.

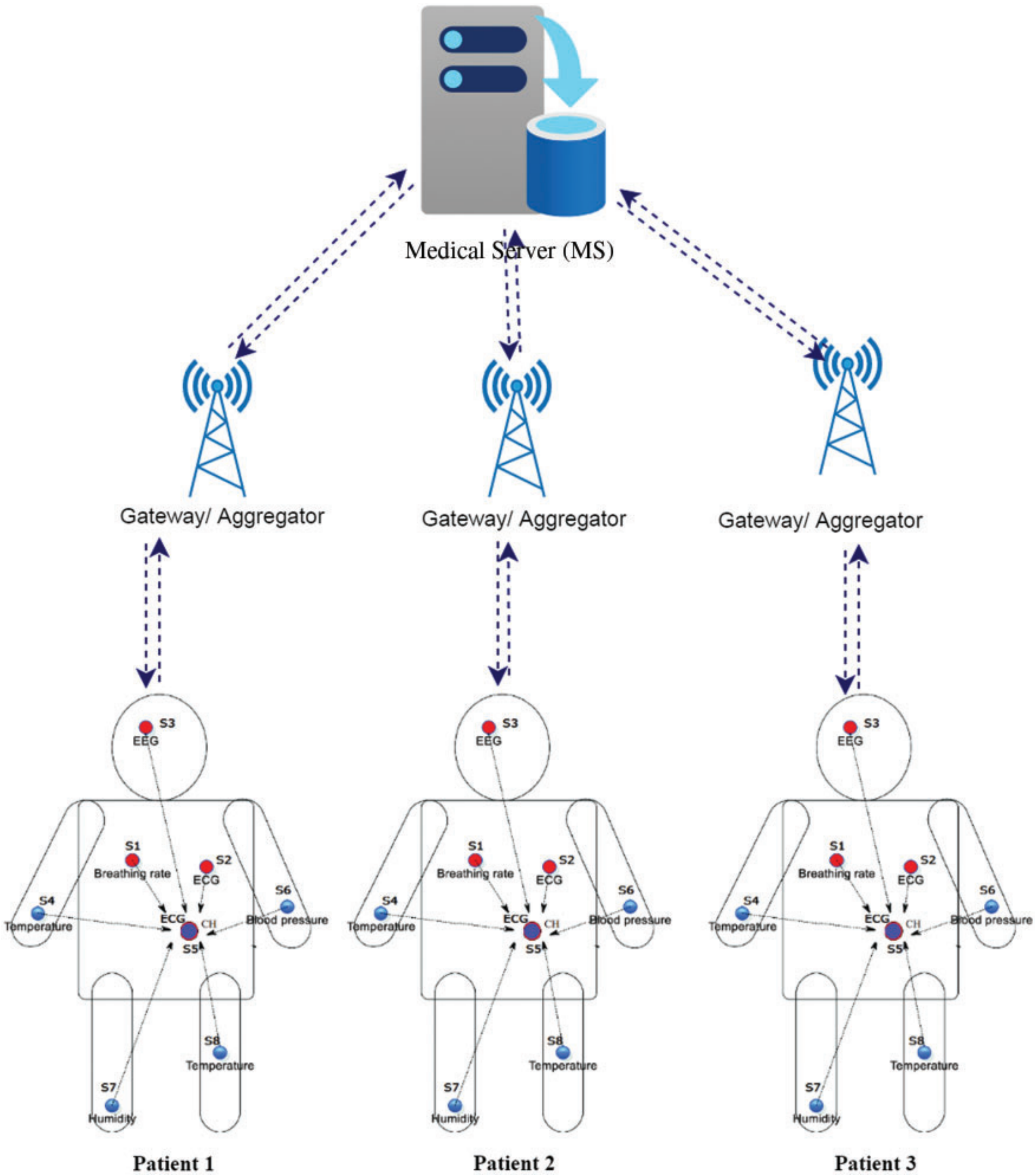

Figure 2: Mobile agent-based real-time data aggregation

3.1.4 Bio-Sensors Clustering and CH Selection

In this section, the detailed procedure is explained for cluster formation and CH selection in WBAN. All bio-sensors fitted on a single are within the CN range, and their facilitated entity is single. Furthermore, there is trust between all bio-sensors of an entity-body. Therefore, we consider the group of bio-sensors within in single body as a cluster. Similarly, all the bio-sensors of each body within the WBANs are grouped into separate clusters, as shown in Fig. 3.

Table 1: Names and notations used in MADA scheme

Variable	Meaning
$\mathbf{R_{max}}$	Maximum transmission range of Bio-sensors
N	Total numbers of Bio-sensors
$\mathbf{S_n}$	The set of all Bio-sensors
$\mathbf{S_{CH}}$	The sets of all cluster headers (CH's)
$\mathbf{I_{CH}}$	There itinerary of MA among CHs
$\mathbf{E_{Rem}}$	The remaining energy of Bio-sensors nodes
CH	Cluster Head

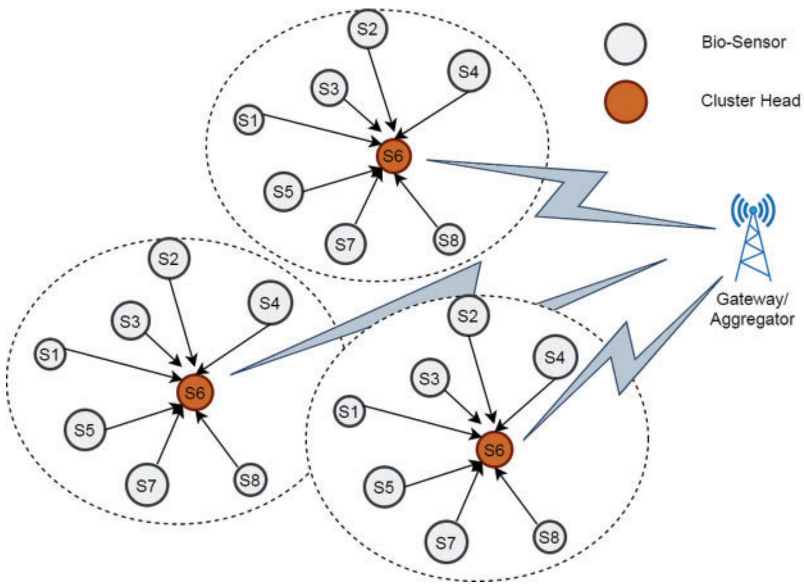

Figure 3: Bio-sensors clustering

According to the LEACH protocol, each bio-sensor node had to assign a rank based on the remaining energy and distance to the sink [10]. The highest rank nodes are elected as a CH for a specific interval of time. This process is repeated after some time for all nodes. The group of CHs is planned for the itinerary in the next phase.

3.1.5 Itinerary Planning among CH Nodes

After the cluster formation and CH selection phase, the next phase is to perform the itinerary planning for MA migration amongst the CHs. For this task minimum spanning tree (MST) has been used. The MS has all the information of bio-sensors i.e., nodes position and their respective coordinates. Therefore, the MS can calculate the weight between CHs. For weight calculation between CHs, we used the following equation.

$$H_x^y = \frac{d(k-1,k)}{W_{max}} \tag{1}$$

W_{max} R_{max} denotes the maximum transmission range. Let us consider x and y to be the two CHs. In the network, and H_x^y is the estimated hop count between x and y CHs. We used the following equation for the weight calculation of the itinerary between any two CHs.

$$w_i = \propto * H_x^y + (1-\beta) * (H_s^x - H_s^y) \quad (2)$$

where, $0 < \alpha \leq 1$ and $0 < \beta \leq 1$ are constant values, while w_i the weight of itinerary between any two CHs. The MA is started from the sink and visit across all CHs by using the weight function that gives minimum cost to the destination point. After the itinerary become established, the next step is to dispatch the MA from the BS to collected the data from CHs.

3.1.6 Fault-Tolerance Based Alternative Itinerary Planning

In this phase, a fault-tolerance based alternate itinerary is planned for data communication from specific bio-sensor nodes and clusters to the BS. The aggregated data are then further transmitted to the MS. This section's key contribution is a fault tolerance-based energy-efficient algorithm for DA in WBAN named Cooperative-FTEA. In which the itinerary is adjusted according to the priority level of the vital sign of efficient DA. As we know that CHs are liable to error because CH is selected from the group of SNs where any error may occur [35,36]. Therefore, planning for the itinerary in WBANs vital sign healthcare monitoring is necessary to bypass the nodes having a fault. There may be a chance of increasing overhead, which can be minimized using cooperative and selecting less-visited CHs.

In some cases, the alternate itinerary is close to the selected typical itinerary that is no longer active. The key reason for that is due to failure in the first itinerary. If a node is no longer active in a cluster, it will not include in the itinerary. Additionally, organizing the alternate itinerary for MA traveling increases the fault-tolerance within the network as shown in Fig. 4.

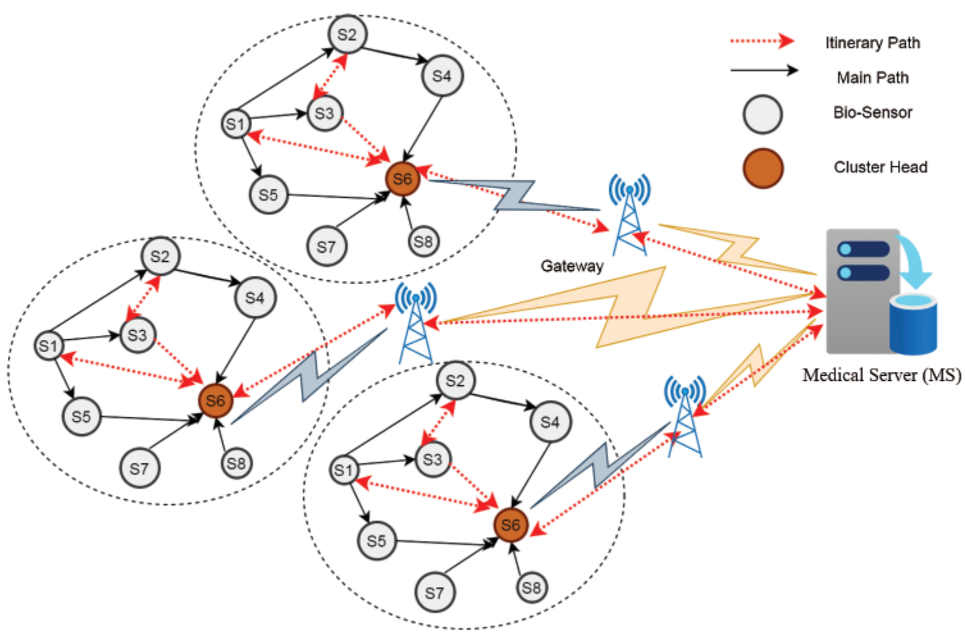

Figure 4: Fault-Tolerant alternate itinerary planning

3.1.7 MA Migration

After organizing the network into clusters and electing a CH for each cluster, an itinerary is a plan among CHs. The BS initiated the MA to collect the data from CHs. Whenever MA visits a cluster for the first time, CHs notify their connected nodes for data collection activities. After visiting all CHs with the network, MA starts collecting data from the last CH and moving back to the BS where data are save in their related MS.

3.2 Operation of MA-Based Data Aggregation

In this section, the operations of MA-Based DA are explained with the help of a flow chart. The detailed flowchart shows how the overall procedure is performed. First of all, the network is deployed, then the clustering of bio-sensors and CH selection is carried out. The next step is MA travel from the sink across all CHs, and finally, alternative itinerary planning is accomplished if in the established path or a node is found erroneous. The flowchart of the proposed scheme is given in Fig. 5.

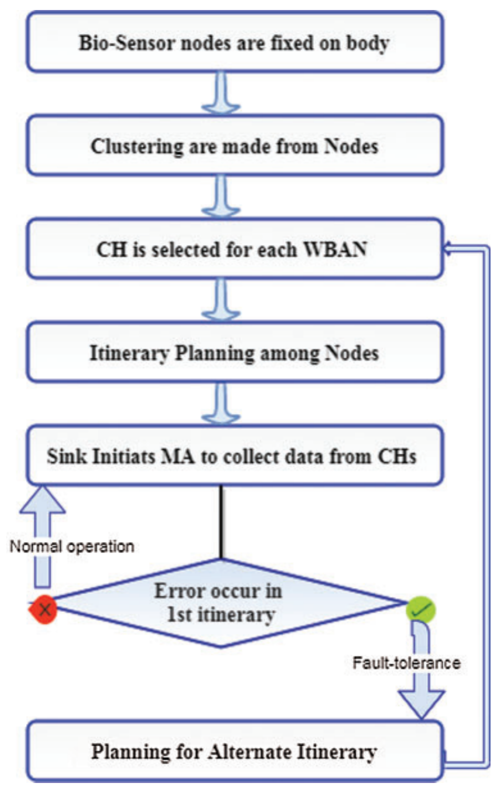

Figure 5: Flowchart of proposed mada scheme

3.3 Algorithmic Pseudocode of MA-Based Data Aggregation

The algorithm for the proposed scheme is developed phase-wise. First, the network is deployed, and CH becomes elected accordingly. After this step, the itinerary is plan and MA is initiated from BS. Finally, for fault-tolerance alternate itinerary planning in case of node or link failures. The detailed algorithmic steps are given below.

Part 1 (Clustering and CH selection)

Step1: Deploy bio-sensors (SN_1, SN_2, SN_3, ... SN_n)

Step 2: Group of bio-sensors related to a WBAN are made into a cluster 'C', and a leader is elected for each know as CH

Step 3: Bio-sensor aggregated data transmission ($(SN_i\,(Sen_{Vital})) \rightarrow CH$

Step 4: Calculate $E_r\,(CH) > Th$ Continue

Step 5: Otherwise, Start from Step 1

Part 2 (Itinerary Planning)

Step 6: Initially, $Itinerary_{CH} = 0$, then

Step 7: while $\exists\,(SN \in I_{CH})$ $\quad do$

Step 8: Set $I_{CH} = I_i(CH_n)$ $\quad end\ while$

Step 9: Sink node generated MA to collect the aggregated data

Step 10: $MA_i \underset{S-D}{\Rightarrow} I_i(CH_n)$

Step 11: Route $Data_{Aggr} \rightarrow Sink$

Part 3 (Fault-Tolerance itinerary planning)

Step 12: if $I_i(CH_n) \rightarrow Sink$

Step 13: if $V \leftarrow V_i(CH_n)$

Step 14: $find$ $\mathrm{I}min_w(u, v)$

Step 15: $Set\, I_i(CH_n \leftarrow I_i(V))\ end\ if$

Step 16: end if

4 Simulation and Network Setup

In this section, the simulation setup of the proposed MA-based real-time energy-efficient DA is discussed. In the simulation setup, Bio-sensor nodes are uniformly distributed in the 5×5 m^2 area. Where SNs are fitted on three patients. Each patient considers a cluster that consists of eight patients. The network topology is set as Fig. 3; the number of clusters is three and the total bio-sensors nodes in this experiment are 24. Moreover, some of the distinct parameters for this experiment are given in Tab. 2.

5 Result Analysis and Evaluation

In this section, the proposed MADA scheme is evaluated using various performance metrics through a simulator. The initial energy of WBAN is considered 8 J. The proposed MADA scheme is evaluated and compared with DAP-DS [6], and EFTA [15] using different performance metrics mention below:

- ♣ Average execution time (AET)
- ♣ Energy consumption
- ♣ Travelled distance (Itinerary length)
- ♣ Packet Delivery Ratio (PDR)
- ♣ End-to-End Delay

Table 2: Simulation parameters

Parameter	Value
Number of Bio-Sensors	24
Monitoring Field magnitude	5×5 m^2
Energy spent by MA (Data Aggregation)	15 nJ
MA immediate delay	10 ms
MA Processing Delay	50 ms
MA Payload	1024 bytes
Collected data size at each CH	200 bytes
Aggregation coefficient	1
Initial Energy of (WBAN)	8 J

The above algorithm is used for MA-based efficient DA. Many notations have been used in this algorithm, some of which are elaborated here. $I_i(CH_n)$ is the selected itinerary for MA migration, $V_i(CH_n)$ is the notation for designated alternate itinerary if an error occurs in the existing itinerary.

5.1 Experiment No.1 – Average Execution Time (AET)

It is also called runtime or latency of specific operation. In the proposed solution, AET is the time MA travels across all CHs plus the time the MA returns to the sink. AET is the time that specific active bio-sensor spend while performing this specific operation. Fig. 6 shows the AET in seconds concerning the number of nodes for the MADA scheme compared with DAP-DS [6] and EFTA [15] schemes.

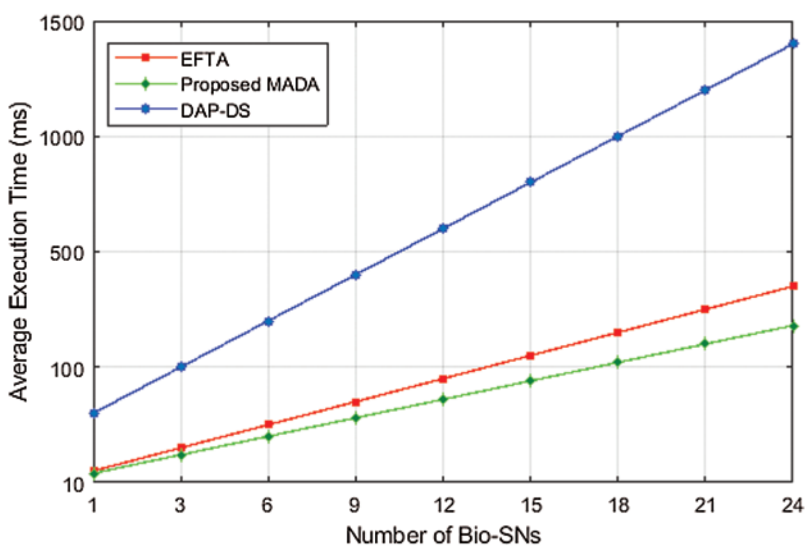

Figure 6: Average execution time *vs.* number of bio-SNs

It can be seen in Fig. 6 that whenever the number of bio-sensor nodes increases, the average execution time also increases. However, the DAP-DS has the highest AET compared to the other two protocols because DAP-DS does not consider MA-based DA. While proposed, MADA and EFTA have nearly the same results. Moreover, our proposed MADA scheme has a relatively better result. Better results are due to MA-based DA with a fault-tolerance provision in WBAN, where each body is considering a separate cluster.

5.2 Experiment No.2 – Energy Consumption

In this experiment, the reduced data transmission MA-based clustering approach has been used. Energy consumption is defined as that how much energy is consumed by applying this algorithm. In this experiment, the basic radio model is used for bio-sensor nodes required for transmitting and receiving data [4]. The energy consumption rate for bio-sensors in WBANs varies significantly based on the schemes that are used for communications. Energy consumption can be calculated supposing that the receiving and transmission of packets as possible when the Radio is On. The energy consumption of transmitting *m*-bit packets at a distance *d* may be formulated in the following formula:

$$E_{TX}(m,d) = \begin{cases} E_{elect} * m + \varepsilon_{amp} * m * d^2 & if\ d < d_0 \\ E_{elect} * m + \varepsilon_{amp} * m * d^4 & if\ d \geq d_0 \end{cases} \tag{3}$$

Similarly, the receiving of m-bits can be calculated as:

$$E_{RX}(m) = \{E_{elect} * m \tag{4}$$

In Eqs. (3) and (4), E_{elect} is the notation for radio intemperance of running the electric circuit during transmission or receiving a message. The value ε_{amp} is used for the transmit amplifier to ensure the smooth operation of the radio, and d_0 is a constant value. The proposed MADA scheme has the lowest energy consumption because of smaller amounts of communication for DA, as shown in Fig. 7.

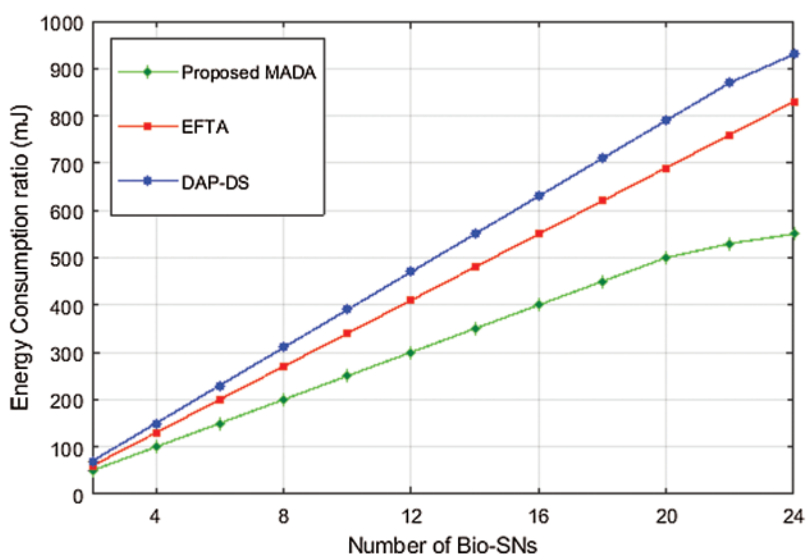

Figure 7: Energy consumption ratio

Fig. 7 demonstrates the overall energy consumption of various bio-sensors in WBANs of the MADA scheme compared with DAP-DS [6] and EFTA [15] protocols. From the resultant graph, it is clear that with the increase in the bio-sensors, energy consumption increases. However, the proposed MADA scheme has the lowest energy consumption due to involving only CHs in itinerary planning in WBAN.

5.3 Experiment No.3 – Travelled Distance (Itinerary Length)

Itinerary length is the distance MA traverse from MS to all CHs and returns to the MS. It is calculated according to the routing table, where the distance between nodes is given. This is important so that to identify the smallest itinerary to the MS from SNs. The smallest itinerary length path is considering for data forwarding in the network. The smallest itinerary length shows less resource utilization because the most resource is utilized during communication in WBANs.

Fig. 8 shows that the total length covered (itinerary) by a MA during DA is compared. The proposed MADA scheme has the shortest itinerary length compared to EFTA and DAP-DS protocols. The short itinerary is due to the strategy that the itinerary is established between those CHs involve in DA for a specific time interval. The protocol DAP-DS has the longest itinerary length because in this protocol, mostly bio-sensors are involved in DA. EFTA protocol has almost the same itinerary length due to MST used in both schemes for itinerary planning. However, EFTA has the maximum distance of CHs from BS due to the comparatively increasing number of itinerary lengths.

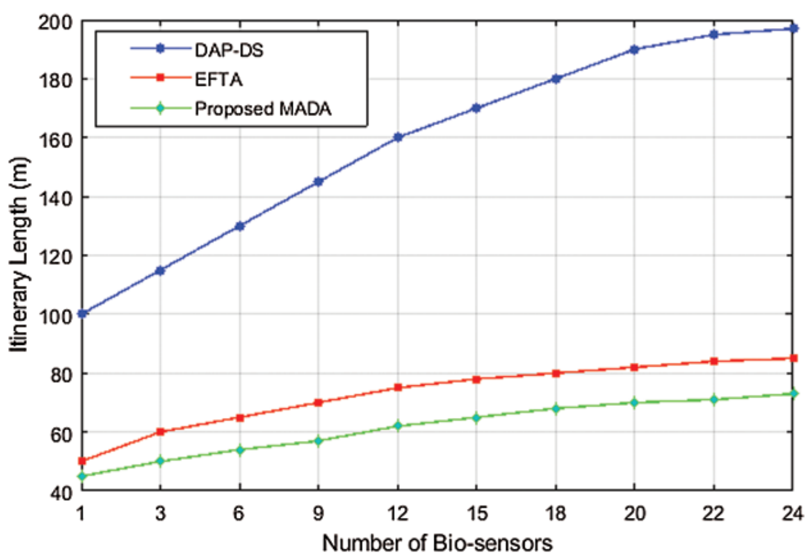

Figure 8: Itinerary length *vs.* bio-sensor nodes

5.4 Experiment No.4 – Packet Delivery Ratio (PDR)

In this experiment, PDR is analysed of the proposed MADA scheme, DAP-DS [6], and EFTA [15] protocols. PDR is defined as the total number of data packets arriving at destinations divided by the total data packets sent from sources. In other words, we can have stated as the Packet delivery ratio is the ratio of the number of packets received at the destination to the number of packets. The packet delivery ratio is calculated in percentage. It is the ratio of packets sent per unit time, which is formulated in the following equation:

$$PDR = Packet\,arrived_t / Total\,packet_R \times 100 \quad (5)$$

Fig. 9 demonstration the PDR for the proposed MADA scheme compared to DAP-DS [6] and EFTA [15] protocols. From the output results, it has been determined that the proposed scheme has a maximum PDR. PDR is continually increasing when the ratio reaches 80%; it becomes stable for all mention schemes. However, the proposed scheme outperformed the other two schemes as its intelligent strategy itinerary planning for DA in WBANs.

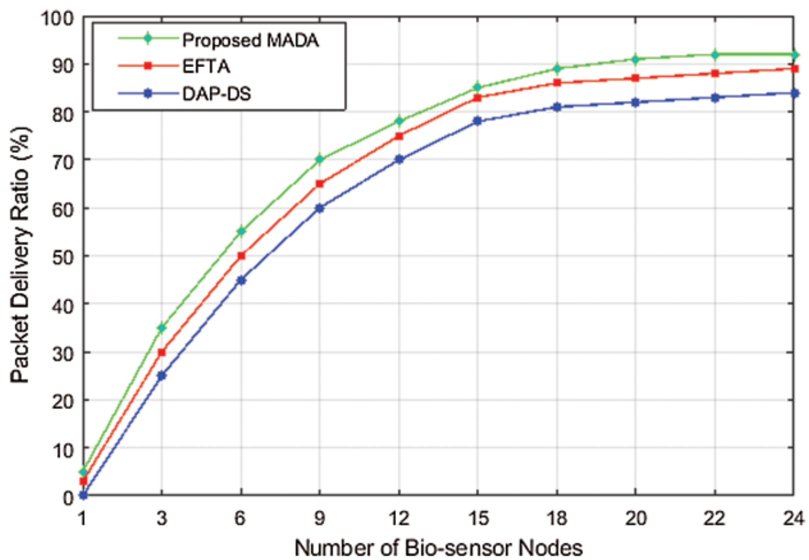

Figure 9: Packet delivery ratio *vs.* bio-sensors

5.5 Experiment No.5 – End-to-End Delay (E2E Delay)

In this experiment, the End-to-End delay is analysed using the proposed MADA scheme and EFTA DAP-DS protocols. E2E delay is the time to send a packet to reach from source to the destination. In WBAN, critical data related to the patient healthcare deal needs minimum delay and time to be delivered to the MS. E2E delay is calculated as when the first packet arrived at the sink in data communication in WBANs [37]. Mathematically, the E2E delay can be calculated as given in Eq. (6).

$$\text{E2E Delay} = \text{T.time}_{\text{SP}} / \text{T}_{\text{RP}} \quad (6)$$

In Eq. (6), $T.time_{SP}$ is total time needed to send the data packets, while T_{RP} represent is the number of total packets received at the sink. In this experiment, the E2E delay is calculated, as shown in the following graph, the experimental setup is the same as the previous experiment.

From Fig. 10, it is palpably shown that the proposed MADA scheme incurs less amount of delay as compared to DAP-DS [6] and EFTA [15] protocols. The minimized E2E delay is due to the efficient itinerary planning and clustering approach for DA in WBANs.

On the other hand, EFTA used the same strategy adopted by the proposed scheme. However, the clustering strategy of the proposed scheme is more energy efficient. DAP-DS encounter longer distance, as distance directly influences the delay; with the increase of distance, E2E delay also increases.

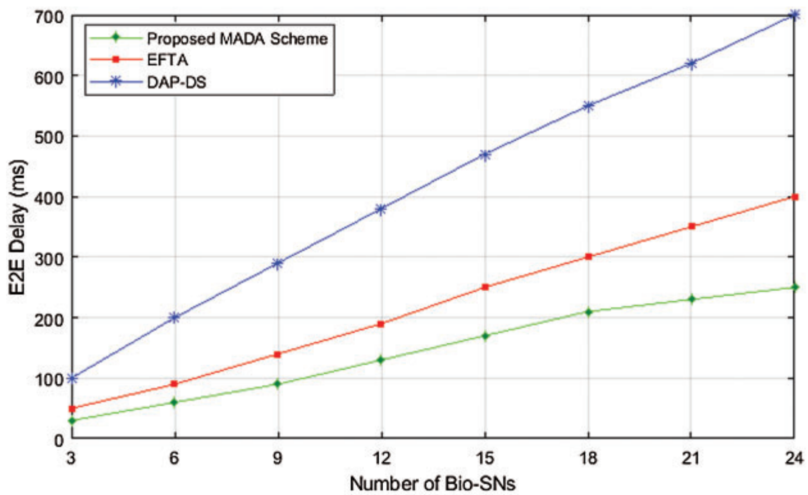

Figure 10: End-to-End delay *vs.* bio-sensor nodes

6 Conclusion and Future Work

In WBANs healthcare applications, delay-sensitive data related to emergency-related services need reliable communication. This paper proposed a novel MADA scheme with agent-based DA in WBANs to improve reliability in WBANs. The proposed MADA scheme increases energy-efficiency, ensures reliable data delivery of critical data packets in healthcare applications. For itinerary planning clustering-based approach is used. Whenever the itinerary is planned, MA travel from MS to all CHs in the network. MA starts collecting aggregated data from the last CH, returning and collecting the aggregated data from all CHs. Whenever an itinerary becomes faulty, an alternate itinerary is planned at runtime, which increases fault-tolerance inside the network. From the simulation results, it is concluded that the proposed scheme outperforms the two benchmark schemes (i.e., EFTA and DAP-DS) and is proven to be an efficient and reliable DA solution for WBANs. The proposed scheme is energy-efficient because it consumes less energy, achieved low end-to-end delay, and increased the packet delivery ratio. Furthermore, fault-tolerance in the network is increased because the alternate itinerary is planned in the cause of failure occur in the current path or a node becomes decline.

In the future, we aim to utilize the sensor cooperation approach with itinerary planning for efficient data aggregation. Then, considerably fault-tolerance and reliability can be achieved with less amount of energy consumption with maximum throughput. The same approach can be adopted for IoT-based WBANs applications.

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