QoS-Aware Heuristic Scheduling with Delay-Constraint for WBSNs

Amit Samanta*†, *Student Member, IEEE*, Yong Li†, *Senior Member, IEEE*, Sheng Chen‡, *Fellow, IEEE*
*Department of Computer Science and Engineering, Indian Institute of Technology Kharagpur, India
†Department of Electronic Engineering, Tsinghua University, Beijing, 100084, China
‡School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK
E-mails: {amitsamanta@sit.iitkgp.ernet.in, liyong07@tsinghua.edu.cn, sqc@ecs.soton.ac.uk}

***Abstract*—Wireless body sensor networks (WBSNs), which efficiently and intelligently sense the physiological signals of the medical patients to support various medial applications, have allured tremendous attention from various research communities. For energy and resource constrained WBSNs, the important issues include: 1) dynamic channel characteristics due to mobility and postural dynamics; 2) high energy efficiency owing to limited battery power; 3) high quality-of-service (QoS) requirement due to critical physiological data. To address the above issues, a cost-effective heuristic packet scheduling scheme is designed to provide the high network throughput and fair QoS to WBSNs. Unlike most of the existing works, we also consider the optimal delay-constraint in order to achieve the optimized packet transmission delay and to manage the heavy traffic load optimally. Specifically, we consider the critical factors of WBSNs to prioritize the data packets among access points, e.g., medical emergent patients have the higher priority to send their data packets than the normal patients. We formulate the proposed scheme mathematically. Simulation results are presented to demonstrate the effectiveness of the proposed heuristic packet scheduling scheme over other existing state-of-the-art solutions, in terms of packet transmission delay, cost and network throughput.**

I. Introduction

Tremendous increase in populations has put enormous burden on our healthcare and transportation systems [1]. Hence, the growing need of efficient healthcare systems is one of the important challenges in smart cities. In order to fulfil the requirement of smart healthcare, wireless body sensor network (WBSN) plays a significant role for modern day healthcare. This important wireless paradigm is gaining tremendous attention in different applications, such as sports, medical emergency and ambulatory systems. Unlike the existing wired and traditional healthcare systems, the body sensor nodes in a WBSN always monitor the vital signals of medical emergent patient in real-time. A WBSN is primarily comprised of one local processing unit (LPU) and several body sensor nodes. Body sensor nodes are generally resource-constrained and small in size, whereas LPUs by comparison are rich in resources, including buffer size and battery-life. The heterogeneous WBSNs inherently monitor the physiological attributes of different medical patients. The sensed physiological attributes are collected by the sensor nodes and transmitted to the LPUs through wireless channels. Afterwards, the LPUs send the amalgamated data to the access points (APs) using Wifi, WiMax and/or 5G technology. The APs in turn transmit the physiological data to the medical servers of smart city. The possessed medical data at medical servers are utilized for the further analysis of medical conditions in real-time, which is vital for the patients to get effective and high-quality help from medical experts.

It can be seen that reliable communications between the various components of this smart healthcare system is essential to maintain its effective operation. Due to irregular postural positions and environments, the links between sensors and LPUs have dynamic characteristics, influenced by limited spectral resource, channel quality variation, path loss and fading [2], [3]. Fading is not only depended on the distance between sensors and LPUs but also affected by the variations of links, such as body posture changes. Therefore, WBSNs need to counter the temporal link failure situations frequently. More critically, because of lightweight system requirement, the body sensors are generally small in size, and hence the resources, such as data processing, buffer size and battery, are exceptionally restricted, in contrast to other sensor nodes. This very limited resource together with link variations increase the delay of the network and lead to huge packet loss in the network. Therefore, it is vital to provide a cost-effective packet scheduling in order to avoid packet loss and to minimize the delay. Most importantly, the aggregated vital signals by body sensors must be disseminated from WBSNs to APs reliably and in time. Hence, the high quality of service (QoS) factors, such as packet loss rate, throughput and delay, must be guaranteed for WBSN-based healthcare systems. Thus, the main contributions of this paper are discussed below.

1. We propose a cost-effective packet scheduling scheme for WBSNs to minimize the data transmission delay, while maintaining high throughput of the network. We also present an optimal admission control scheme for WBSNs to provide fair recourse sharing among them for efficient data packet transmission.
2. We consider the human postural dynamics and group-based mobility model in designing the cost-effective packet scheduling algorithm. We also consider the optimal delay-constraint for efficient packet scheduling. Thus, we estimate the total delay for WBSNs in order to minimize the packet transmission delay.
3. Simulation results demonstrate that our algorithm can

effectively schedule the data traffic from WBSNs to APs. The results also show that the proposed scheme provides higher throughput while minimizing packet transmission delay. It also yields the best performance, in terms of service utility and packet loss rate, under different mobility dynamics, compared with other solutions.

The rest of the paper is organized as follows. Section II describes the related work. In Section III, we present the system model for WBSNs. Section IV describes an optimal admission control mechanism for WBSNs. Subsequently, a cost-effective heuristic scheduling scheme for WBSNs is investigated in Section V, in particular, our cost-effective heuristic scheduling with optimal delay-constraint is proposed. Section VI conducts extensive simulations to validate our proposed scheme, and Section VII concludes the paper.

II. Related Work

The problem of packet scheduling for WBSNs in the presence of mobility and postural dynamics is a challenging task. Over the years, only a few researchers have addressed some of the important issues related to this problem. Quwaider and Biswas [3] studied the DTN-based routing for WBSNs in the presence of dynamic postural partitioning. Wang *et al.* [4] proposed a cooperative scheduling for coexisting WBSNs in order to mitigate the mutual interference among them. Ullah [5] proposed a RFID-enabled MAC protocol for WBSNs to increase the network throughput. Javaid *et al.* [6] designed a routing protocol for WBSNs to optimize the energy consumption rate. Ullah and Alamri [7] proposed a secured RFID-based WBSN communications. Rezvani and Ghorashi [8] proposed channel-based resource allocation for WBSNs with context-aware property. Sandhu *et al.* [9] proposed a data forwarding scheme with load balance in WBSNs to minimize the energy consumption rate. Sun *et al.* [10] designed an inter-user interference management scheme for WBSNs. Ullah *et al.* [11] proposed an incentive-based optimal scheduling for residential users to optimize the power consumption rate. Sipal *et al.* [12] analyzed the impact of hub/LPU locations in WBSNs. Samanta *et al.* [13] proposed an optimal resource distribution algorithm with efficient load balance in WBSNs. Munasinghe *et al.* [14] proposed an efficient coordinator/LPU placement algorithm for WBSNs. Ibarra *et al.* [15] proposed a QoS-aware energy-harvesting scheme for WBSNs. Habib *et al.* [16] proposed a self-adaptive data collection and fusion scheme for WBSNs. Deepak and Babu [17] proposed a data frame transmission mechanism to improve reliability in WBSNs.

In summary, most for the existing studies [4]–[11], [15], [17] mainly focus on the energy-efficient data scheduling and transmission in WBSNs. They did not consider the effect of postural and mobility dynamics in WBSNs. As discussed previously, postural and mobility dynamics inherently decreases the data transmission rate in WBSNs, which reduces the network throughput and also increases the delay. This motivates us to study cost-effective packet scheduling with optimal delay-constraint to minimize the packet transmission delay, while maintaining high throughput, under various postural and mobility dynamics.

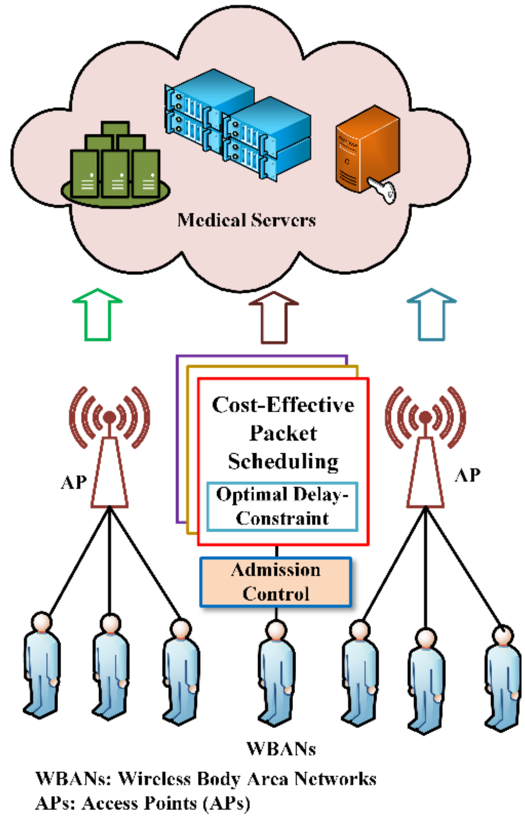


Figure 1: QoS-aware heuristic scheduling for WBSNs

III. System Architecture

Consider $\mathcal{N}$ WBSNs, denoted by $\mathcal{S} = \{S_1, S_2, \cdots, S_{\mathcal{N}}\}$, coexisting to provide reliable medical signals, as shown in Figure 1. In each WBSN, n body sensors, denoted by $S_i = \{s_{i,1}, s_{i,2}, \cdots, s_{i,n}\}$, are positioned over the human body to observe the indispensable medical signals of the patient. Following the sensing mechanism, the body sensors forward the accumulated medical data to the related LPUs, denoted by $\mathcal{G} = \{G_1, G_2, \cdots, G_{\mathcal{N}}\}$, and the LPUs disseminate the medical packets to the corresponding APs, denoted by $\mathcal{A} = \{A_1, A_2, \cdots, A_{\mathcal{M}}\}$. The medical packets arrive at an LPU following the Poisson distribution with rate λ, and the dissemination of medial packets are synchronized according to the packet criticality factor [13]. WBSNs generally follow the group-based mobility model [2] and the IEEE 802.15.6 standard [18]. Due to mobility, WBSNs face a certain packet loss rate denoted as P_{ls}. According to the standard, each sensor node has some predefined traffic designations. WBSNs are instinctively restricted in terms of available resource.

To forward their data streams effectively, however, WBSNs require fair amount of resources. We assume that the WBSN S_i has a maximum $\mathcal{B}_i^{max}$ and a minimum $\mathcal{B}_i^{min}$ resource requirements to forward the medical packets to APs. We also consider the criticality factor $\Phi_i^t \in (0,\ 1)$ at time t, which quantifies the medical condition of the associated sensor-equipped medical patient. We further denote the remaining energy of a WBSN S_i by $\mathbb{E}_i^{re}$. Along with energy consumption, it is necessary to minimize the packet transmission delay and cost in order to preserve the fair QoS between WBSNs. The packet transmission cost for a WBSN S_i at time t is denoted by $\mathcal{Y}_{tran,i}^t$. On the other hand, to cope with the network dynamics, the power consumption rate will increase significantly, which decreases the resource availability of WBSNs considerably. Therefore, cost-effective packet scheduling is necessary to minimize the packet transmission delay and cost, while maintaining the QoS requirements of the network.

IV. Admission Control Mechanism

Before packet scheduling it is important to allocate fair amount of resources to individual WBSNs for ensuring efficient packet transmission, and optimal admission control is very necessary, particularly in dense hospital area, since the limited resources cannot meet the transmission demands of all WBSNs. Hence, we consider the heterogeneous priorities and traffic demands of WBSNs, and we design optimal admission control mechanism to satisfy as many high-priority WBSNs as possible, while fulfilling the minimum traffic demands of the requested WBSNs. Once all the high-priority WBSNs have been satisfied, in terms of their traffic demands, the low-priority WBSNs are allowed with the resources. The minimum traffic demand τ_i of WBSN S_i is the minimum amount of packets to be disseminated by S_i through a time-frame. Then the minimum transmission time demand θ_i of S_i is given by

$$\theta_i = \frac{\tau_i}{z_i} < \mathcal{T}, \tag{1}$$

where z_i is the transmission rate of WBSN S_i and $\mathcal{T}$ denotes the total time frame structure with an equal frame length.

The decision variable Y_i for this admission control mechanism is defined as:

$$Y_i = \begin{cases} 1, & S_i \text{ uses the system,} \\ 0, & \text{otherwise.} \end{cases} \tag{2}$$

That is, $Y_i = 1$ if WBSN S_i uses the system; otherwise, $Y_i = 0$. We also design a decision variable J_{ij} based on the distance-based interference model [19] to identify the interference among WBSNs, so as to avoid congestion in data transmission. Specifically $J_{i,j}$ is is defined as:

$$J_{ij} = \begin{cases} 1, & d_{ij} \le d^{th}, \\ 0, & d_{ij} > d^{th}, \end{cases} \tag{3}$$

where d_{ij} is the distance between S_i and A_j and d^{th} denotes the threshold distance. Thus, if $J_{ij} = 1$, WBSN S_i faces the interference; otherwise there is no interference.

Hence, the optimization problem associated with this admission control mechanism for WBSNs is formulated as:

$$\textbf{(P1)}: \underset{t_k>0, Y_i\in\{0,1\}}{\text{maximize}} \sum_{i\in\mathcal{N}} \sum_{t\in\mathcal{T}} \theta_i \Phi_i^t, \tag{4}$$

$$\text{Subject to} \quad \sum_{k=1}^{|\mathcal{T}|} t_k \le \mathcal{T}, \tag{5}$$

$$d_{ij} \ge d^{th}, i \in \mathcal{N}, j \in M \tag{6}$$

$$\tau_i \ge \tau_{th}, i \in n, \tag{7}$$

$$z_i \ge z_{th}, i \in n, \tag{8}$$

Detail description of this approach is discussed. (4) describes the main objective function for optimal admission control. (5) t_k represents the time assignment to a WBSN S_i in a time frame. The actual distance between WBSNs and APs, d_{ij}, is to be greater than the threshold distance, d^{th}, as shown in (6). (7) represents that the minimum traffic demand, τ_i, is to be grater than the threshold traffic demand, τ_{th}. The present transmission rate, z_i, is to be greater than the threshold transmission rate, z_{th}, as shown in (8).

V. HPS: Heuristic Packet Scheduling

Due to mobility and postural dynamics, the packet transmission delay and cost increases in network, which inherently minimizes the QoS of WBSNs. In order to improve the QoS of WBSNs, here we discuss a cost-effective heuristic packet scheduling scheme with optimal delay constraint. At first, we need to estimate the total delay encountered by WBSNs in the network to design the optimal delay-constraint. Later, we propose a cost-effective packet scheduling algorithm, while taking into consideration of critical priority of WBSNs.

Estimation of Effective Delay: The total delay encountered by WBSNs is estimated based on the *data transfer* and *data execution* delays. They are discussed in details below.

Definition 1. *The data transfer delay $\mathcal{D}_{TF}^t$ between a WBSN S_i and an AP A_j is depended on the time required to send a certain data size using predefined bandwidth and the delay encountered by existing communication link. Mathematically,*

$$\mathcal{D}_{TF}^t = \left(\frac{\mathcal{D}_{ij}}{\mathcal{B}_{ij}^t} + \mathcal{D}_{li}^t \right) \tag{9}$$

where $\mathcal{D}_{ij}$ denotes the total data size need to be transferred through the link l_{ij}, $\mathcal{B}_{ij}^t$ denotes the bandwidth associated to link l_{ij} and $\mathcal{D}_{li}^t$ denotes the delay encountered (due to congestion in network) by the existing communication link l_{ij}^t.*

Definition 2. *The data execution delay $\mathcal{D}_{EX}^t$ is directly proportional to the workloads on WBSN. It is defined as $\mathcal{D}_{EX}^t = \frac{\mathcal{W}_i^t}{p_i^t}$. Here, $\mathcal{W}_i^t$ and p_i^t denote the data traffic and processing power of WBSN S_i at time t, respectively.*

Hence, the total estimated delay $\mathcal{D}_{tot}^t$ for WBSN S_i is the addition of both data data transfer delay $\mathcal{D}_{TF}^t$ and execution

*The communication link between WBSN S_i and AP A_i is denoted by l_{ij}. If there exist a communication link between WBSN S_i and AP A_i then the value of l_{ij} will be 1 otherwise 0.

delay $\mathcal{D}^t_{EX}$, which is mathematically expressed as:

$$\begin{aligned}\mathcal{D}^t_{tot} &= \mathcal{D}^t_{TF} + \mathcal{D}^t_{EX}\\ &= \left(\frac{\mathcal{D}_{ij}}{\mathcal{B}^t_{ij}} + \mathcal{D}^t_{li}\right) + \frac{\mathcal{W}^t_i}{p^t_i}\end{aligned} \tag{10}$$

A. Cost-Effective Packet Scheduling

After estimation of total delay, now we model a cost-effective packet scheduling scheme for WBSNs to provide optimized packet transmission delay and cost. With the loss of generality, we assume that the medical data packets require $\mathcal{T}$ slots to disseminate them efficiently. Here, we assume a time frame with different time slots. We describe the length of time slot and index of time-slot by t and $t \in \mathcal{T} = \{1, 2, \cdots, \}$, respectively. In a time-slot, if more than one WBSN choose a particular channel for data packet dissemination, then we use the carrier sense multiple access (CSMA) mechanism to overcome the possible collisions in the network. For a WBSN who successfully get a dedicated channel, it will gain the throughput of one unit in terms of single packet per time-slot.

Definition 3. *The decision profile $\mathbb{Z}$ of WBSNs is denoted by a set of data dissemination decision variables, $\mathbb{Z} = \{\mathcal{Z}_1, \mathcal{Z}_2, \cdots, \mathcal{Z}_\mathcal{N}\}$. The data dissemination decision variable of a WBSN is depended on the successful access to a wireless channel without having any collision in the network for efficient data packets dissemination. Mathematically,*

$$\mathcal{Z} = \begin{cases} 1, & \textit{access to a channel}, \\ 0, & \textit{otherwise}, \end{cases} \tag{11}$$

If a WBSN gets a free channel, then it transmits its data packets efficiently; else it has to wait for next time-slot.

Definition 4. *The transmission rate of WBSN S_i that selects a wireless channel H to disseminates its data packets is mathematically expressed as:*

$$\mathcal{F}_i(\mathcal{Z}, t) = \sigma_i(\mathcal{Z}, t), \tag{12}$$

where $\sigma_i(\mathcal{Z}, t)$ indicates whether WBSN S_i successfully contends the channel in slot t, which is defined as:

$$\sigma_{\mathcal{Z},t} = \begin{cases} 1, & \textit{WBSN } S_i \textit{ successfully contends a channel}, \\ 0, & \textit{otherwise}, \end{cases}$$

Definition 5. *By following CSMA principle, $\sigma_{\mathcal{Z},t}$ is a Bernoulli random variable. The probability mass function of $\sigma_{\mathcal{Z},t}$ is defined as:*

$$Pr(\sigma_{\mathcal{Z},t}) = \begin{cases} \frac{1}{\mathbb{G}_{v_\mathcal{N}}}, & \textit{if } \sigma_{\mathcal{Z},t} = 1 \ , \\ 1 - \frac{1}{\mathbb{G}_{v_\mathcal{N}}}, & \textit{otherwise}, \end{cases} \tag{13}$$

where $\frac{1}{\mathbb{G}_{v_\mathcal{N}}}$ denotes the number of WBSNs that select channel H for data dissemination.

Definition 6. *The QoS constraint is defined as the ratio of total number of successful packet transmissions from sensor nodes and the total service delay of data dissemination. It is defined as:*

$$\mathcal{Q}^{con}_i(t) = \frac{E[e] \times P^{ul+dl}_i(t)}{\sum_{i \in n} \sum_{t \in T} \left(D^i_q(t) + D^i_{tran}(t) + D^i_{prop}(t)\right)}, \tag{14}$$

where $E[e]$ denotes the expected payload size of data packets, $P^{ul+dl}_i(t)$ denotes the number of packets transmitted from sensor node b_i for both up-link and down-link at time t, and $D^i_q(t)$, $D^i_{tran}(t)$, and $D^i_{prop}(t)$ denote the queueing delay, data transmission delay and propagation delay.

Definition 7. *The expected throughput achieved by a WBSN S_i while taking into consideration the decision profile $\mathbb{Z}$ is defined as:*

$$\phi_i = \frac{1}{\mathbb{G}_{v_\mathcal{N}}} \tag{15}$$

where, $\frac{1}{\mathbb{G}_{v_\mathcal{N}}}$ denotes the number of WBSNs that select channel H for data dissemination.

Definition 8. *The packet transmission cost is depended on the inflow and outflow data dissemination cost. Mathematically,*

$$\mathcal{Y}_{tran,i} = \sum_{i \in \mathcal{N}} \sum_{j \in M} \sum_{l \in \mathcal{L}} \sum_{t \in \mathcal{T}} \left[\Gamma \in^{ij}_{ij}(t) x^t_{ul} + \Xi \in^{out}_{ji}(t) y^t_{dl}\right], \tag{16}$$

where Γ and Ξ denote the unit price for both static inflow and outflow traffics. $\in^{ij}_{ij}(t)$ and $\in^{out}_{ji}(t)$ denote the inflow and outflow data dissemination at time t. x^t_{ul} and y^t_{dl} denote the unit data processing price for uplink and downlink at time t, respectively. Here, $l = \{ul, dl\}$, $\forall l \in \mathcal{L}$, $\mathcal{L}$ denotes the set of unlinks and downlinks.

Definition 9. *The profit level $\mathbb{P}_i$ of WBSN S_i is defined as the function of value gained from qualified critical data $\mathbb{H}$ and reward for disseminating the data $\mathcal{R}$. Mathematically,*

$$\mathbb{P}(\mathcal{Y}_{tran,i}, \mathbb{R}) = \begin{cases} 0, & \mathbb{R} < \mathcal{Y}_{tran,i}, \\ \mathbb{H} - \mathbb{R}, & \mathbb{R} \geq \mathcal{Y}_{tran,i}, \end{cases} \tag{17}$$

where $\mathcal{Y}_{tran,i}$ denotes the data dissemination cost of WBSN S_i. As the distribution of $\mathcal{Y}_{tran,i}$ is independent of value $\mathbb{H}$ and reward $\mathbb{R}$ [20], the expected profit is defined as:

$$\begin{aligned}\mathbb{P}_i &= \int_0^\infty \mathbb{P}(\mathcal{Y}_{tran,i}, \mathbb{R}) f(\mathcal{Y}_{tran,i}) d\mathcal{Y}^t_{tran,i},\\ &= \int_0^\mathbb{R} (\mathbb{H} - \mathbb{R}) f(\mathcal{Y}^t_{tran,i}) d\mathcal{Y}^t_{tran,i} = F(\mathbb{R})(\mathbb{H} - \mathbb{R}).\end{aligned} \tag{18}$$

B. Utility Maximization Framework

Using the Definitions 3 – 9, we formulate an utility function $\mathcal{U}_i$ for heuristic scheduling among WBSNs and APs, which is mathematically expressed as:

$$\mathcal{U}_i = \left(\Upsilon_1 \mathcal{F}_i(\mathcal{Z}, t) \mathcal{Q}^{con}_i(t) + \Upsilon_2 \left[\frac{\phi_i}{\phi_{th}} + \frac{\mathbb{P}_i}{\mathbb{P}_{th}}\right] - \frac{\mathcal{Y}_{tran,i}}{\mathcal{Y}_{tran,th}}\right), \tag{19}$$

where Υ_1 and Υ_2 denotes the coefficient factors for heuristic scheduling. $\mathcal{Y}_{tran,th}$ is the threshold packet transmission cost. Having computed the utility function of each WBSN, the

WBSN with the maximum utility value emerges as the winner and get to disseminate its data packets first than the others. Thus, without the loss of generality, we can formulate the optimization problem as:

$$\textbf{(P2)}: \underset{t>0,\sigma_{\mathcal{Z},t}\in\{0,1\}}{\text{maximize}} \sum_{i\in\mathcal{N}} \mathcal{U}_i, \tag{20}$$

$$\text{Subject to} \quad \gamma_{th} \leq \gamma_i, i \in \mathcal{N}, \tag{21}$$

$$\phi_i \geq \phi_{th}, i \in \mathcal{N}, \tag{22}$$

$$\mathbb{P}_i \geq \mathbb{P}_{th}, i \in \mathcal{N}, \tag{23}$$

$$\mathcal{Q}_i^{con}(t) \geq \mathcal{Q}_{th}^{con}(t), i \in \mathcal{N}, \tag{24}$$

$$\mathcal{Y}_{tran,i} \geq \mathcal{Y}_{tran,th}, i \in \mathcal{N}, \tag{25}$$

Detail description of this approach is discussed. (20) presents the primary optimization function for heuristic scheduling. (21) describes that the actual signal strength for receiving power, γ_i, is to be greater than the threshold signal strength for receiving power, γ_{th}. The expected throughput of the network, ϕ_i, is to be greater than the threshold data network thoughput, ϕ_{th}, as shown in (22). (23) represents that the profit of WBSNs, $\mathbb{P}_i$, is to be grater than the threshold profit value, $\mathbb{P}_{th}$. The QoS constraint, $\mathcal{Q}_i^{con}(t)$, is to be greater than the threshold QoS constraint, $\mathcal{Q}_{th}^{con}(t)$, as shown in (25). (23) denotes that the packet transmission cost of WBSNs, $\mathcal{Y}_{tran,i}$, is to be grater than the threshold packet transmission cost, $\mathcal{Y}_{tran,th}$. Solving the optimization problem using Lagrangian Multipliers, we get,

$$\begin{aligned}\Psi_{\mathbb{U}} = \sum_{i=1}^{\mathcal{N}} \frac{\Phi_i^t}{\mathbb{U}_{th}} \Psi_i\Big(\phi_i, \mathbb{P}_i, \mathcal{Q}_i^{con}(t), \mathcal{Y}_{tran,i}, \mathcal{F}_i(\mathcal{Z},t)\Big) \\ -\beta_1\Big(\sum_{i=1}^{\mathcal{N}}\gamma_i - \gamma_{th}\Big) - \beta_2\Big(\sum_{i=1}^{\mathcal{N}}\phi_i - \phi_{th}\Big) \\ -\beta_3\Big(\sum_{i=1}^{\mathcal{N}}\mathbb{P}_i - \mathbb{P}_{th}\Big) - \beta_4\Big(\sum_{i=1}^{\mathcal{N}}\mathcal{Q}_i^{con}(t) - \mathcal{Q}_{th}^{con}(t)\Big).\end{aligned}$$

where β_1, β_2, β_3 and β_4 denote the different constraints for Lagrangian Multipliers and Φ_i^t denotes criticality factor of WBSNs based on the traffic designations [18]. Hence, our main objective is to maximize the value of $\mathcal{U}_i$ using the Lagrange Multiplier.

Here, we discuss the algorithm for the heuristic packet scheduling scheme. As shown in Algorithm 1, first, we need to provide three inputs – set of WBSNs $\mathcal{S}$, set of APs A, and total time T. In the presence of mobility and postural dynamics, the data transmission rate decreases inherently. Hence, we proposed heuristic packet scheduling scheme to optimize the apcket transmission delay and cost in the network. Initially, we set the waiting time T_{wa} to 0. Thereafter, for each WBSN S_i, we conduct the scheduling algorithm. When the total time less than the waiting time, i.e., $\mathcal{T} < T_{wa}$, then we create a decision profile $\mathcal{Z}$. Afterward, we estimate packet transmission rate $\mathcal{F}_i(\mathcal{Z},t)$ and calculate QoS constraint $\mathcal{Q}_i^{con}(t)$. Also, we estimate packet transmission cost $\mathcal{Y}_{tran,i}$ and calculate profit level $\mathbb{P}_i$. Using the estimated and calculated variables, we design a utility function $\mathcal{U}_i$ for heuristic scheduling. If the utility function $\mathcal{U}_i$ greater than the threshold utility function $\mathcal{U}_{th}$, then we update the set of WBSNs $\bar{\mathcal{S}} = \mathcal{S} \cap S_i$. Also,

Algorithm 1 Algorithm for Heuristic Packet Scheduling

Inputs:
- Set of WBSNs ($\mathcal{S}$), set of APs A and total time $\mathcal{T}$.

Output: Optimized transmission cost $\bar{\mathcal{Y}}_{tran}$ and waiting time T_{wa}.

Set $T_{wa} = 0$.
Set $\mathcal{S} = \mathcal{N}$ and $A = M$.
for each WBSN S_i **do**
  if $\mathcal{T} < T_{wa}$ **then**
    First, create a decision profile $\mathcal{Z}$.
    Estimate packet transmission rate $\mathcal{F}_i(\mathcal{Z},t)$.
    Calculate QoS constraint $\mathcal{Q}_i^{con}(t)$.
    Estimate packet transmission cost $\mathcal{Y}_{tran,i}$.
    Calculate profit level $\mathbb{P}_i$.
    Design utility function $\mathcal{U}_i$.
    if $\mathcal{U}_i \geq \mathcal{U}_{th}$ **then**
      Updated set of WBSNs $\bar{\mathcal{S}} = \mathcal{S} \cap S_i$.
      Optimized transmission cost $\bar{\mathcal{Y}}_{tran}$.
      Update waiting time $T_{wa} = T_{wa}$.
    else
      Updated set of WBSNs $\mathcal{S} = \mathcal{S}$.
      Non-optimal transmission cost ($\widehat{\mathcal{Y}}_{tran}$).
      Update waiting time $T_{wa} = T_{wa} + 1$.
    end if
  end if
end for
Return $\bar{\mathcal{Y}}_{tran}$ and T_{wa}.

we update the waiting time T_{wa} is updated as well. Along with, we also get the optimized transmission cost $\bar{\mathcal{Y}}_{tran}$ using Lagrangian Multiplier. The process is stopped, when the waiting time crosses a predefined maximum waiting time T_{wa}^{max}. To optimize the packet transmission cost for WBSNs using (20), we use the Lagrangian optimization technique to get the optimal value.

VI. Performance Evaluation

We present simulation results of the proposed scheme – CHANCE[†] in compare to existing schemes. The simulation parameters used in the experiments are shown in Table I.

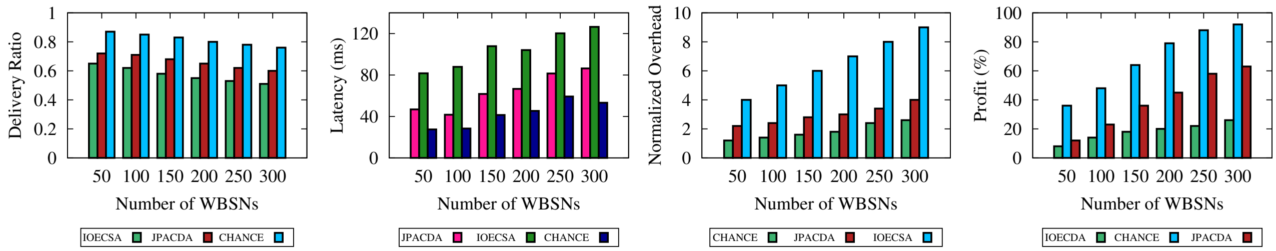
Table I: Simulation Parameters

Parameter	Value
Simulation area	5 Km $\times$5 Km
Total time	500 s
# of WBSNs	100-300
# of body sensors	8
Initial energy of WBSN	0.5 J
Velocity	1.5-2.5 m/s
Tx-energy consumption	16.7 nJ
RX-energy consumption	36.1 nJ
Amp energy consumption	1.97 nJ
Sensing range	0.5-1.5 m
Packet generation rate	4 packets/sec
Packet size	512 Bytes

A. Experimental Setup

In this section, we analyze the performance of the proposed scheme — CHANCE. Here, we have considered 300 WBSNs, here they are distributed randomly in an area of 5×5 Km. Each WBSN comprised of 6 sensor nodes and they are planted in the

[†]The Cost-effective Heuristic scheduling and AdmissioN Control with dElay constraint scheme for WBSNs is called CHANCE.



(a) Delivery Ratio (b) Latency (c) Overhead (d) Profit

Figure 2: Analysis of delivery ratio, latency, overhead and profit

Table II: Specification of sensor types and coordinates [21]

Sensor type	Data rate (kbps)	Placement Coordinate
1) ECG	71 kbps	$(10, 155)$
2) Motion	35 kbps	$(30, 132)$
3) EEG	43.2 kbps	$(28, 110)$
4) Glucose	1.6 kbps	$(14, 78)$
5) EMG	100 kbps	$(7, 50)$
6) EMG	100 kbps	$(30, 50)$
7) Motion	35 kbps	$(7, 0)$
8) Motion	35 kbps	$(30, 0)$

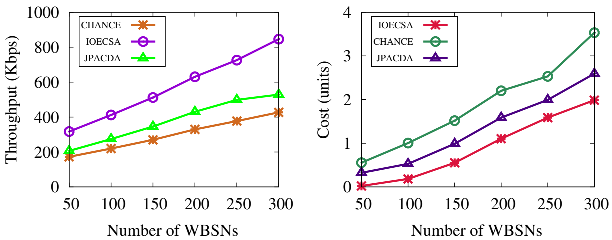
human body according to the specifications [21]. To design the mobility of WBSNs, we have considered the Group-based mobility of WBSNs [2]. On the other hand, we have considered a fading technique Raleigh for the communication between sensor nodes and LPUs, where the Raleigh path loss varies within $1.8 - 2.9$. Consequently, we have considered a shadow fading technique Log-normal for the communication between LPUs and APs, where the Log-normal shadow path loss varies within $3 - 3.4$ [10]. We also consider the packet size of 512 Bytes for the intra-BAN and inter-BAN communications. The data dissemination between sensor nodes and LPUs, and LPUs to APs follows the single-hop star topology.

B. Benchmarks

Here, we consider two existing schemes — JPACDA proposed by Cui *et al.* [21] and IOECSA proposed by Ullah *et al.* [11] to compare them with the proposed scheme. JPACDA [21] is a scheme for joint power allocation and coordinator deployment in WBSNs to minimize the energy consumption for sensor service and power constraints. The authors jointly considered several issues such as – *optimal QoS-requirements*, *channel characteristics*, and *human body postures*. By solving this problem, the authors achieved the optimal transmission power and coordinator location. IOECSA [11] is an incentive mechanism for optimal energy consumption scheduling scheme. Here, the authors exhibited an energy efficient optimization model based on Binary Particle Swarm Optimization (BPSO) to minimize the cost. It also considers a dynamic pricing environment to provide the incentives to end users, which apparently save the energy consumption rate. The scheme inherently minimizes the data transmission delay and provide minimum cost to users. These two schemes are apt for the comparison, as they considered joint scheduling and cost minimization problem and these two works are upto date state-of-the-art solutions.

C. Results and Discussion

Figure 2(a) shows the packet delivery ratio in the network for varying number of WBSNs in the presence of mobility and postural dynamics. As in the presence of mobility and postural dynamics, the packet delivery ratio of WBSNs decreases, therefore we proposed a heuristic packet scheduling algorithm to maximize the packet delivery ratio. From the figure, we observe that the packet delivery ratio using proposed approach – *CHANCE* increases with the variation in number of WBSNs. We also compared our proposed scheme with existing schemes – *JPACDA* and *IOECSA*, where we observe our scheme perform better in terms of packet delivery ratio by 12% and 17%, respectively. Figure 2(b) presents the packet delivery latency for varying number of WBSNs. From the figure, we observe that the cumulative latency incurs due to data packet dissemination for the increasing number of WBSNs. To optimize the packet delivery latency, we proposed a heuristic packet scheduling algorithm, using that we are able to minimize the packet delivery latency than the existing approaches – *JPACDA* and *IOECSA*. Hence, our proposed approach – *CHANCE* outperforms the existing approaches by 25% and 34%, respectively. Figure 2(c) shows the total overhead of the network for varying number of WBSNs. From the figure, we oversee that the system overhead for the proposed scheme – *CHANCE* increases with the increase in number of WBSNs. However, we observe that the proposed approach – *CHANCE* is able to provide the optimal system overhead to WBSNs. Therefore, the energy consumption of WBSNs decreases, while the other approaches fail to provide optimized system overhead to WBSNs. The proposed approach outperforms the existing approaches – *JPACDA* and *IOECSA* by 32% and 45%, respectively. Figure 2(d) provides the normalized profit level for the varying number of WBSNs. In the presence of mobility and postural partitioning, the profit level of WBSN increases using the proposed approach as WBSNs is able to disseminate its critical data packets with minimum packet loss. However, the other existing approaches fail to provide fair profit margin to WBSNs. But, our proposed scheme – *CHANCE* provides heuristic packet scheduling algorithm with delay-commentary to WBSNs, which inherently decreases the packet loss rate and maximize the profit level of WBSNs. The proposed approach provides better performance to WBSNs than the other approaches like –*JPACDA* and *IOECSA* by 26% and 46%, respectively.



(a) Throughput (b) Cost

Figure 3: Analysis of throughput and cost

Figure 3(a) presents the throughput of the network in the presence of mobility and postural dynamics. From the figure, we observe that the throughput of the network for WBSNs using our proposed scheme – *CHANCE* is higher, therefore the fairness among WBSNs increases using our scheme. As the proposed approach provides fair resources to WBSNs using the optimal admission control mechanism, therefore the probability of successfully data dissemination increases in the network. Hence, the throughput of the network increases in the presence of mobility and postural dynamics. We also compared our scheme with the existing approaches, where our approach outperforms the existing approach by $15 - 18\%$. Figure 3(b) shows the packet delivery cost of WBSNs in the presence of mobility and postural dynamics. From the figure, we observe that the cost decreases for WBSNs using our proposed scheme – *CHANCE*, as we provide a heuristic packet scheduling algorithm with delay-constraint for WBSNs. We observe that the packet delivery cost using our proposed approach is lesser than the existing approach – *JPACDA* and *IOECSA*. The proposed approach – *CHANCE* out performs others in terms of packet delivery cost by 7% and 9%.

VII. Conclusion

In this work, we proposed a cost-effective heuristic scheduling and admission control for WBSNs in the presence of mobility and postural dynamics. Firstly, we proposed an optimal admission control to provide a fair amount of resources to WBSNs for efficient packet transmission. We also propose a cost-effective heuristic packet scheduling scheme to minimize the packet delivery delay and cost for WBSNs. The proposed approach shows remarkable development in terms of network throughput, packet delivery delay and cost. As future work, we will implement the proposed approach with real-bed information and hardware implication. We also propose to have an optimal data dissemination scheme for WBSNs in the presence of mobility and postural dynamics.

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