Energy-aware Management in Wireless Body Area Network System

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Abstract

Recently, Wireless Body Area Network (WBAN) has promise to revolutionize human daily life. The need for multiple sensors and constant monitoring lead these systems to be energy hungry and expensive with short operating lifetimes. In this paper, we offer a review of existing work of WBAN and focus on energy-aware management in it. We emphasize that *nodes computation*, *wireless communication*, *topology deployment* and *energy scavenging* are main domains for making a long-lived WBAN. We study the popular power management technique Dynamic Voltage and Frequency Scaling (DVFS) and identify the impact of slack time in Dynamic Power Management (DPM), and finally propose an enhanced dynamic power management method to schedule scaled jobs at slack time with the goal of saving energy and keeping system reliability. Theoretical and experimental evaluations exhibit the effectiveness and efficiency of the proposed method.

Keywords: Wireless Body Area Network, energy efficient, task scheduling, DVFS, slack time

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1. Introduction

For the last few decades, Wireless Body Area Network (WBAN) has encountered a growing interest with the scientific community as well as industry, which is built to serve a variety of healthcare, consumer electronics and entertainment applications for human beings. WBAN is different from wireless sensor networks (WSN), where tiny sensor nodes are deployed on the surface or implanted inside human body to monitor vital body parameters and movements for medical health diagnosis. Recently, WBAN is mainly deployed in medical domains with the main idea to remove all wires connecting sensors on the patient, and establishes a wireless network. Other application areas could be athlete monitoring, soldier surveillance and animal care with the consideration of WBAN protocol standardization [1].

The IEEE defines WBAN together with another network type near human body, the Wireless Personal Area Network (WPAN). The largest difference between a WBAN and WPAN lies in the data rates. WPANs use technologies like Bluetooth to support sustained rates of up to 3 Mbit/s, which is significantly higher than the envisioned rates from sensors on the human body. As it is shown in **Fig. 1,** there are other related technologies in the wireless network arena. We compare WBAN with Wireless Personal (WPAN), Wireless Local (WLAN) and Wireless Metropolitan (WMAN) in an onion model with the consideration of communication range.

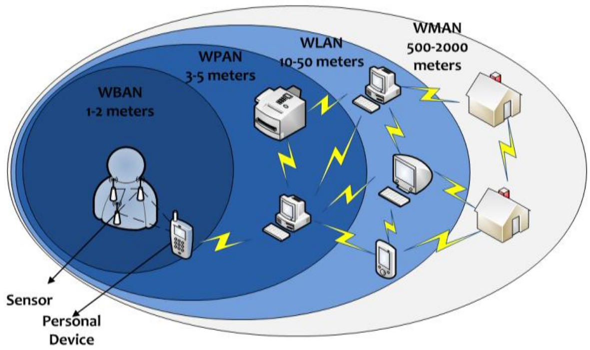


Fig. 1. Onion model of wireless networks

However, the WBAN faces some technical problems that remain to be solved, one of which is saving energy in a device with limited battery life. This is a critical problem especially for an implanted device as it is impossible or very difficult to replace or recharge the battery. In order to have a long monitor time, it is mandatory to have long lived sensor nodes, and hence, power optimization at node level becomes equally important as well as power optimization at network level [2].

Energy-aware management is critical in order to increase the lifespan of sensor nodes. Energy consumption can be divided into three main domains: sensing, wireless communication and data processing [3]. A lot of research has been done to obtain a long-lived WBAN, where low power hardware is a fundamental requirement [4]. An overview of energy saving in wireless sensor networks has been established [5]. Much research has focused on reducing wireless communication power consumption and methods have been proposed [6][7]. Existing research suggests that shutting down processing units may optimize topology and communication range [8][9][10] . Network traffic and routing is exploited to decide when to turn the node into the sleeping state from an ON state and this has been shown to lower power consumption significantly [11]. However, topology control and energy-aware routing protocols only reduce the transmission power of radio, and hence, are not suitable for low workload applications or the radio platforms with high idle power consumption. Sleep scheduling protocols can reduce the idle power consumption, however they are not effective with high network workloads or low radio idle power consumption.

Although wireless communication is the major activity that consumes power for transmission, power consumption of microcontroller or processor units also have significant impact on energy budgets in WBAN nodes [12][13]. For example, the energy consumption of the widely adopted Mica2 sensor node is studied very accurately and shown that the power consumption of processors range from 28 % to 86% of the total power consumed, or roughly 50% on average [14].

In [12], the effect of network congestion on buffer congestion was analyzed and it was shown that reducing the speed of the microcontroller during congestion periods can save power. However, this is only applicable in WSN; there is seldom congestion problem in WBAN. Traditionally required expensive wiring installation or routine battery changes motivate wireless autonomous transducer solutions (WATS), which make energy harvesting essential in WBAN. However, due to the small size of sensor nodes and other limitations, energy scavenging will only deliver small amounts of energy [15][16], which involves further challenges in the design of sensor nodes with ultra low power consumption.

Existing energy-aware management work towards WBAN can be divided into four domains on *nodes computation* (*processing*), *wireless communication*, *topology deployment* and *energy scavenging.* Our focus is on the power optimization at microcontroller or processor units with the ultimate aim to increase the lifetime of WBAN, which is *nodes computation* (*processing*) level. The existing work on Dynamic Frequency Scaling (DFS) and Dynamic Voltage Scaling (DVS) techniques reveals efficiencies in power consumption reduction when the processor is at an idle state [17]. DVFS technique has proven to be a highly effective method of achieving low power consumption for the system on chip (SOC) while meeting performance requirements. This is due to the fact that extending the service lifetime of these systems by reducing their power dissipation is a key requirement [18]. Idle state is not an isolated or discrete phenomenon in the processor unit. It is integrated with all the working procedures of the sensor node. However, as WBANs are mainly deployed to sense some rare events for human health care, most of the time there is not much traffic in the network and not much work for the sensor nodes to carry. The problem arises when a node is turned ON but there is not much work to carry, and hence, remains idle for a longer duration. For example, sensor nodes with fixed service rates are designed to handle moderate data arrival rates. However, if a WBAN system is in a catastrophic period, this will result in data loss due to buffer overflow. And if designed to handle peak data rates it will remain idle over a longer period with much power wastage. This will reduce the lifetime of sensor nodes. Thus, idle state is not only caused by data processing, but also by the communication size.

In the recent past, many research studies explored the problem of minimizing energy consumption while meeting the deadlines for various real-time task models by exploiting the available static and/or dynamic slack in the system [19][20][21][22]. Instead of using all the available slack for DVFS to save energy, one can reserve a portion of the slack to schedule a recovery job R_J for any job J whose execution is scaled down, to recuperate the reliability loss due to the energy management [19][22]. Our primary objective for node computation energy reduction is to improve a periodic real-time tasks scheduling algorithm with slack sorting to execute on a uni-processor system.

The remainder of this paper is organized as follows. First, we give an introduction of WBAN in Section 2, and review the previous work in energy efficiency in Section 3. Section 4 addresses the DVFS and slack time task scheduling to save power in WBAN. We perform theoretical analysis and preliminary experiments to evaluate our proposed method in Section 5 and draw a conclusion in Section 6.

2. Wireless Body Area Network

Wireless body area network is gaining worldwide attention for ubiquitous healthcare [23]. It facilitates patients, especially elderly people and disabled people who are facing the problems in moving around and cannot visit the doctor frequently. As it is shown in **Fig. 2**, a typical WBAN has two components: Intra-Body and Extra-Body [24]. In the Intra-Body part, sensors equipped around/inside the patient are used to continuously monitor physiological parameters. For example, sensors are placed to measure the temperature, blood pressure, heart rate, respiration rate, etc. If a sensor notices a problem, a signal can be sent to require real time treatment. Each WBAN will have one special node, the sink or personal device which could be a smart device that receives all signal information from low level sensors, and finally sends data to medical workers who will make a diagnosis in the Extra-Body part.

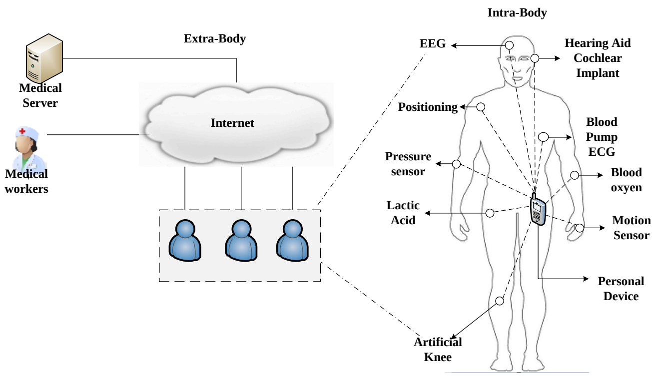


Fig. 2. A common architecture of WBAN

WBAN was first advocated for health monitoring applications in an academic research paper more than 10 years ago [25]. It has similarities with WSN, which forms a network with various sensor nodes [23][26][27][28][29][30][31][32][33]. However, we argue that there are several differences that make WBAN more challenging.

· Architecture

WBAN comprises of smaller number of sensor nodes, while WSN has many;

Sensor nodes are diffcult to be replaced in in-body WBAN, while it is easy to do in WSN;

WBAN has a center device to collect and process data from sensor nodes, while in WSN there could be more than one node to maintain sensor nodes in a distributed system.

New types of sensors may be required at anytime in WBAN, while they are not needed in WSN after is has been deployed for some purpose.

· Data

Correlation of different type of data is important for WBAN to make decisions, while in WSN this is not a concern.

· Communication

Generally there is one hop to a center device in WBAN and few communications between sensor nodes, while multi hop exists in WSN.

Heterogeneous or periodic data rates exist in WBAN, while it is homogeneous in WSN.

· Energy

Reliability is critical of energy efficiency method in WBAN, while seldom considered in WSN.

Energy scavenging is from patients in WBAN, while it comes from the environment in WSN.

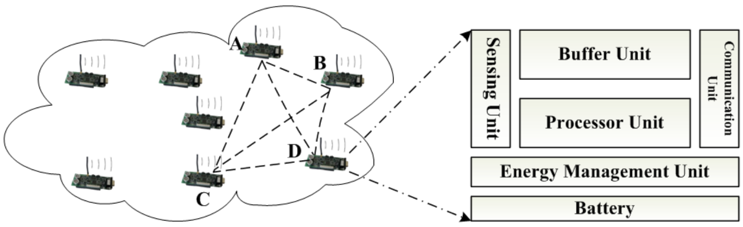


Fig. 3. Architecture of Sensor Nodes

While WBAN is discussed with different architectures, the components of sensor nodes are similar. As it is shown in **Fig. 3**, low level sensor data arrives at sensor nodes from two sources: data sensed by its own sensors and data received from neighboring nodes. For example, {A, B, C, D} are four sensors deployed in a wireless body area network with the same basic architecture. Sensor node A can receive data from its own sensor attached at somewhere, also it can receive information from neighboring sensors {B, C, D} through a reception module via a topology network. Various standards for WBAN are defined to provide efficient means of data transfer and communications including Bluetooth, Zigbee, Ant, MICS, UWB and some custom protocols. Energy consumption is considered as important as data communications in WBAN, as we conclude the energy efficiency related work in Section 3.

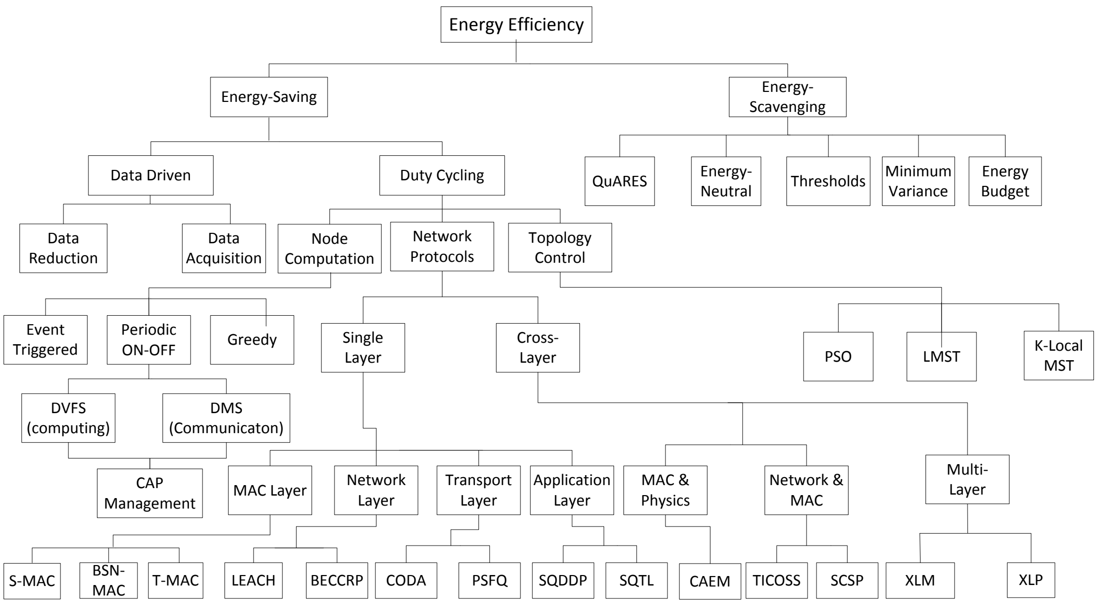


Fig. 4. Energy-aware Wireless Body Area Network

3. Energy Efficiency Related Work

Limited hardware capabilities and very limited battery power supply are the two main constraints for Wireless Body Area Networks. Power optimization is highly desired at all the levels in order to have a long lifetime for Wireless Body Area Network (WBAN). We review the existing work according the four categories proposed in Section 1 and give an overview of existing research in energy-aware WBAN in **Fig. 4**. Energy efficiency methods can be divided into four categories: wireless communication level, node computation level, energy scavenging level and topology level. Topology level energy efficiency methods are generally considered in WSN for a complex network. To the best of our knowledge, there is very little work on topology design for energy management in WBAN [32], which could be an open issue in the future of cloud-assisted WBAN. In this section, we mainly discuss the other three areas.

3.1 Wireless Communication Level

Both WSN and WBAN systems need specific implications at each layer of the protocol stack. Reasonable and efficient communication protocols can promote energy efficiency in WBANs or WSNs, without considering cross-layer or multi-layer protocols. A lot of researchers have worked on the development of suitable communication protocols [26].

- Physical Layer [34][35]

How the human body reacts to RF communications and the complications in WBAN are unique challenges, which are not present in other types of sensor networks.

- Mac Layer [36][37][38][39]

The transmission of RF signals is a major overhead for the energy efficiency in WBAN, which is an active area of research. Various WBAN specific MAC layer schemes are proposed focusing on the key feature of greater energy efficiency and QoS [26], while overhearing, idle listening and collisions are mainly considered in WSN for energy efficiency.

- Network Layer [40][41]

As WBAN works in a heterogeneous or periodic data rate, the required routing algorithm complexity within WBANs should be low in comparison to large-scale WSNs.

- Transport Layer [42][43][44]

TCP and UPD are too heavyweight and complex for WBAN. The design of energy efficient transport protocols for reliable packet delivery is a challenge in this area.

- Application Layer [27][45]

SQDDP (Sensor Query and Data Dissemination Protocol) [27] and SQTL (Sensor Query and Tasking Language) [45] are proposed in application layer. Any application specific QoS constraints are handled at this level together with any data compression and signal processing, however there has been little work on protocols operating at the application layer.

- Cross- Layer [46][47][48][49][50]

Due to the characteristics of WBAN in network heterogeneity, QoS, channel conditions and performance, the traditional layered approach are not suitable for WBAN. Cross-Layer can offer a lot of advantages for energy efficiency in WBAN systems, which combines two or more layers to improve the efficiency communication between protocols.

3.2 Node Computation Level

In most WBAN systems, the sensor nodes have a time varying computational load, which must be considered to optimize computing energy. A lot of work has been done with dynamic voltage and frequency scaling (DVFS) for reducing energy consumption in WSN. DVFS exploits this fact by dynamically adapting the processor's supply voltage and operating frequency to satisfy the instantaneous processing requirement. The concept of dynamic voltage scaling is nicely elaborated in [17][51].

Ravinagarajan et al. proposed a task scheduler based on a Liner Regression Model embedded with Dynamic Voltage and Frequency Scaling (DVFS) functionality, which can improve the average accuracy of a Structural Health Monitoring (SHM) measurement [52]. Considering small sized sensor nodes cannot store the increased data arrival at one time without data loss, an adaptive threshold policy for selecting a particular state of sensor node has been studied in [53]. By using a Coordinated Adaptive Power management method that combines the Dynamic Voltage Frequency Scaling (DVFS) and Dynamic Modulation Scaling (DMS), we can improve the lifetime of sensor nodes and reduce the data loss before transmission. In order to optimize power at individual nodes along with the reduction in data loss due to buffer congestion, Joshi et al., proposed to coordinate the service rates of computation unit and communication unit on a sensor node which gives rise to Coordinated Adaptive Power (CAP) management [2]. Another adaptive algorithm to adjust the processor operating frequency under the timing and energy constraints based on the real-time workload is proposed in [54], which utilizes the maximum task slack for energy saving.

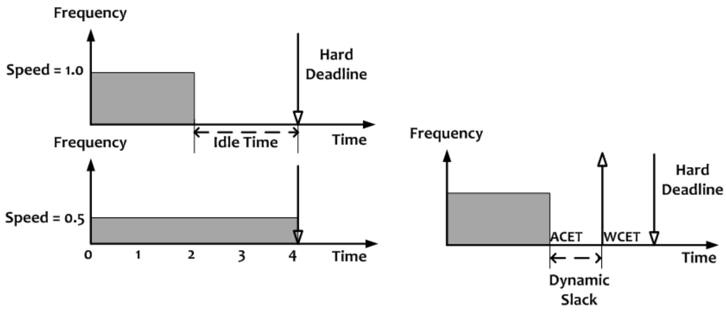
3.3 Energy Scavenging Level

Limited battery energy constraints can be overcome if the battery is recharged using energy scavenging and harvesting techniques. Much research [55][56][57][58][59] has been proposed in order to develop an energy harvesting wireless sensor network, which seems to overcome the stringent power constraint problems.

Recent research has enabled wireless sensor nodes to harvest energy from surrounding environments. An adaptive duty cycling algorithm that allows energy harvesting sensor nodes to autonomously adjust the duty cycle according to the energy availability in the environment is proposed in [60]. A two stage adaptive energy scavenging management framework QuARES is proposed in [61], which exploits application tolerance to quality degradation to adjust application quality based on energy harvesting conditions.

4. Slack Time Based Energy Management

We focus on energy optimization at node computation level with the ultimate aim to increase the lifespan of WBAN. Wireless communication and data processing consume moderate amount of energy consumption at wireless sensor nodes. Real-Time DVFS (RT-DVFS) is a branch of DVFS, which reduces CPU energy consumption through DVFS, while at the same time it ensures that task-time constraints are satisfied by constructing appropriate real-time task schedules [62]. A hard real-time constraint is critical for health care applications in WBAN, which must be guaranteed to help medical personnel take immediate action when a dangerous event is signaled from the sensors. While DVFS involves adjusting CPU voltage and frequency, Dynamic Power Management (DPM) [63][64][65] involves transition unit and processor into low-power/sleep states. However, scaling down the clock frequency may cause deadline misses and serious catastrophe. Hence, reliability should be considered as important as energy efficiency. In this paper, we propose a comprehensive energy reduction method for periodic real-time tasks while preserving system reliability in a WBAN environment.



(a) (b)

Fig. 5. Idle and slack time example. (a) Idle Time (b) Slack Time

Reducing the idle power consumption during the normal period and reducing the buffer overflow during the catastrophic period are equally important [2]. As it is shown in **Fig. 5**, this idle state power consumption represents power wastage as power is consumed without doing anything. Hence, it is important to control the power consumption during ON state by reducing idle time periods. In WBAN, normal period is the time interval when an event of interest has not occurred and everything is normal, which results in small data transmission rates in sensor nodes. Catastrophic period is the time duration when some event occurs and an overflow of information is sensed by the nodes and transferred between neighborhood sensor nodes and personal devices at a peak rate.

We propose to keep a sensor node at sleep state during normal periods and perform a frequency scale and slack based task schedule during catastrophic periods. We describe our energy model and assumptions in follows.

4.1 Model and Assumptions

We give the model definition and assumptions in this section. We follow the basic idea of DVFS in [66][67] that the maximum frequency of operation is dependent on the supply voltage in most CMOS based processors.

$$f = k \times \frac{(V_{dd} - V_t)^2}{V_{dd}} \tag{1}$$

Where, V_{dd} is the supply voltage and f is the clock frequency. There will be a dynamic power consumption denoted as $P_d = C_{ef} \times V_{dd}{}^2 \times f$ with a CPU frequency *f*. Here, C_{ef} is the effective switch capacitance. And thus we can obtain $P_d = \alpha \times f^3$, which exhibits that the dynamic power consumption of a processor is directly proportional to the cube of CPU frequency [67].

We give our assumptions as follows:

1. We assume that the WCET C_i of task T_i is given under the maximum processing speed f_{max} and the execution time of a task scales linearly with the processing speed. That is, at speed *f*, the execution time of task T_i is assumed to be $C_i \cdot \frac{f_{\max}}{f}$.
2. The power consumption *P* of a computing system is given by:

$$P = P_s +^{-} h(P_{ind} + P_d) = P_s +^{-} h(P_{ind} + \alpha f^3) \tag{2}$$

Where

P_s is the *static power*, which maintain basic circuits and keep the clock running;

P_{ind} is the *frequency-independent active power*, which can be efficiently removed by switch into sleep mode.
P_d is the *frequency-dependent active power*, which includes processor's dynamic power and any power that depends on system processing speeds.
$\bar{h}$ is the parameter to indicate whether the system status. The value 1 means the system is in computation, while 0 means in sleep mode or off mode.

3. Assume that the system reliability is satisfactory when no power management scheme is applied, even under the worst-case scenario (i.e., when jobs take their WCETs).

According to the above definition and assumptions, we can evaluate the execution time of each job and its energy consumption. The earlier research [19][22] defined a wrapper-task mechanism to track/manage dynamic slack and allocate to scaled task for recovery. For any dynamic slack generated, a new wrapper-task will be created with two timing parameters: *size* and *deadline*. As it is shown in **Fig. 6**, size indicates the amount of dynamic slack generated, and a deadline is equal to that of the job whose early completion gave rise to this slack. The wrapper-task could be destroyed when all the slack it represents is reclaimed or wasted. We analyze the potential problem in RA-DPM [19] and argue that a sorted wrapper task queue (WT-Queue) with the size of slack time may improve the performance in the next section.

4.2 Problems

Four periodic real-time tasks $\tau = \{T_1(1,6), T_2(6,10), T_3(2,15), T_4(3,30)\}$ are defined for our example task set. For jobs with the same deadline, the one with the smaller task index is assumed to have higher priority. Similar to ready jobs that are kept in the ready queue (*Ready-Q*), wrapper-tasks are kept in a *WT-Queue* in increasing order of their deadlines.

A non-scaled job will reclaim the slack only if the amount of reclaimable slack is larger than the job size [19]. Thus, at time 3, J_{31} reclaims the available slack and scales down its execution as shown in **Fig. 6**.

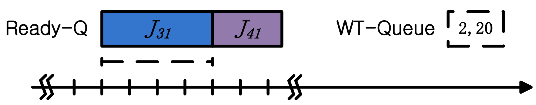


Fig. 6. Non-scaled job time & reclaimable slack time problem

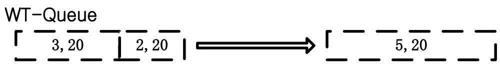
However, there may be a serious problem when considering reclaimable slack size. The scenario shown in **Fig. 6**, J_{31} is expected to be executed in 4 CPU time slices. The slack time generated by the previous job in the *WT-Queue* only contains 2 slices, which means the reclaimable slack is not enough for the job to be processed. The earlier research *RA-DPM* ignores this scenario and may miss a better scheduling method and energy saving performance.

4.2 Method Description

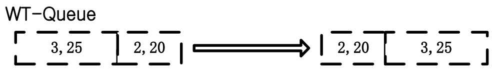
In order to solve the problem proposed in **Fig. 6**, we proposed to sort *WT-Queue* with the size of slack time. There are three ways to manage *WT-Queue* for better performance. As shown in **Fig. 7**:

1) Slack time with the same deadline should be merged in order to perform a long-time job. As shown in **Fig. 7** (a), 2 slacks should be merged as a new slack with size 5.

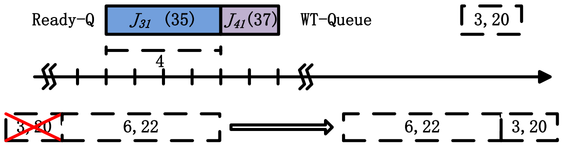
2) Two slack times should be kept in the *WT-Queue* in increasing order of their deadlines as shown in **Fig. 7** (b).
3) Slack times need further sorting with the size of slack in DESC.



(a) Merge with same deadline



(b) Sort with deadline in DESC



(c) Sort with slack time size in DESC

Fig. 7. Slack time sorting in *WT-Queue*

We describe the third way with example **Fig. 7**(c) in detail. According to research [19], J_{31} cannot be scaled to execute because the slack size is not large enough. The slack (3, 20) will be skipped and J_{31} will wait for a new slack time that has enough slack size (e.g. (6, 22)). To solve this problem, we propose to sort the order of slack time in *WT-Queue* with two constraints:

(1) *Slack size* constraint

All the slacks in *WT-Queue* with large slack size may have high priorities.

(2) *Deadline* constraint

All the slacks in *WT-Queue* with earlier deadline than current job deadline may have high priorities.

These two constraints must be considered together, which means only the slack has larger size and the earlier deadline should have higher priority. For example, assume J_{31} has a deadline of 35 and there are two slacks in current WT-Queue S_1(3, 20) and S_2(6, 22). By performing the proposed constraint sorting, we may have a new WT-Queue as (6, 22) and (3, 20). Obviously, J_{31} could be scaled to execute with new WT-Queue. The scaled execution of J_{31} uses the time slots of the reclaimed slack and is scaled at speed 4/6 = 2/3, while RJ_{31} will take J_{31}'s original time slots. If J_{31} can finish as early as time 18, then J_{41} may reclaim slack (3, 20) which means all the slack time could be scheduled. Then all the generated slacks will be reclaimable.

5. Theoretical and Experimental Analysis

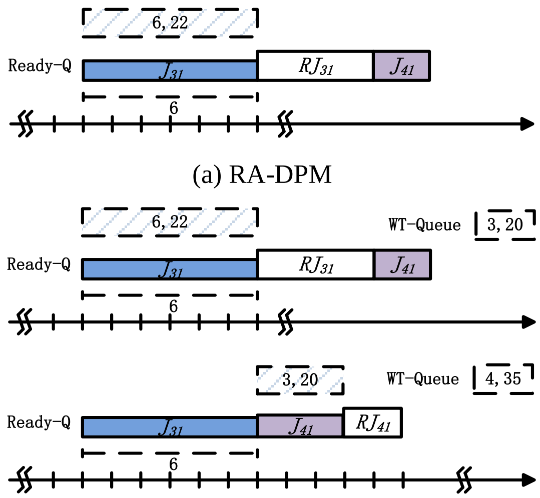
5.1 Theoretical Evaluation

We evaluate our method with a detailed example as follows:

For a periodic real-time task set with utilization *U*, we consider the problem of how to use the spare CPU utilization (*1-U*), as well as the dynamic slack generated at run-time, for maximizing energy savings while keeping the reliability of any job of task T_i.

Fig. 8 (b) shows the new scheduling assignment with proposed method. Although S_2 (6, 22) was generated after S_1, it may be assigned a high priority and scaled J_{31} to be executed during this slack period with CPU speed at 4/6=2/3. Compared with **Fig. 8** (a), slack time (3, 20) could be used for a future job.

Fig. 9 showed that according to our proposed method, longer slack time will be first used to lower the CPU frequency, which will save energy consumption when $f > f_{ee}$.



(a) RA-DPM

(b) Slack time sorted RA-DPM

Fig. 8. Comparison of different slack time

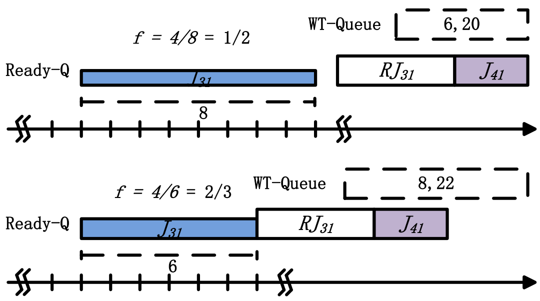


Fig. 9. Usage of Longer Slack Time

Our proposed method is based on RA-DPM that has already been proven a better performer when dealing with a periodic real-time tasks scheduling algorithm that executes on a uni-processor system for saving energy consumption. We may also guarantee the reliability of the proposed scheduling with saving energy consumption. Our proposed method has three main contributions:

1) Scale job with larger slack size may have lower CPU frequencies which helps us to obtain smaller power consumption. Intuitively, when executing a given job, lower frequencies result in less frequency-dependent active energy consumption.

2) The more the available dynamic slack is allocated for energy management, the lower the processing frequency can be for executing job J_k, *and thus more energy savings* can be obtained.
3) Recovery Job is used to guarantee to preserve the reliability of a real-time job, and sorted WT-Queue can improve the performance.

5.2 Experimental Analysis

To evaluate our proposed method, we choose 3 programs (*adpcm*, *fft1k* and *matmul*) from SNU real-time benchmarks [68] and perform simulation in Sim-Panalyzer [69], WCET is analyzed with HEPTANE tool [70]. A DVFS-enabled processor similar to the XScale processor is used in the simulation, where the actual XScale processor power and frequency setting is shown in **Table 1** [71]. For simply implementation, we do not consider the overhead from processor voltage and frequency switching. Also, we ignore the power consumption during sleep mode.

Table 1. XScale processor power and frequency level

Frequency(MHz)	150	400	600	800	1000
Voltage(V)	0.75	1.0	1.3	1.6	1.8
Power(mW)	80	170	400	900	1600
Slowdown factor	0.15	0.4	0.6	0.8	1.0
Idle power(mW)	45				

We conduct this experiment to help us understand the energy consumption when the slack time varies and thus impact of our proposed RT-DVFS. As it is shown in **Fig. 10** and **Table 1,** we only consider energy consumption during run and idle state, while ignore sleep mode that consume very few power. We implemented two profiles as p1 and p2 on *fft1k* program, which p1 indicates scaling job with smaller dynamic slack time (lower ratio of ACET/WCET), p2 indicates scaling with larger dynamic slack time(larger ratio of ACET/WCET). It is obvious that before scaling when ACET/WCET=1, they have same energy consumption. As ACET/WCET decrease, we can see that p2 consume small energy compared with p1. This is coincident with proposed contribution 1) and 2) in theoretical evaluation.

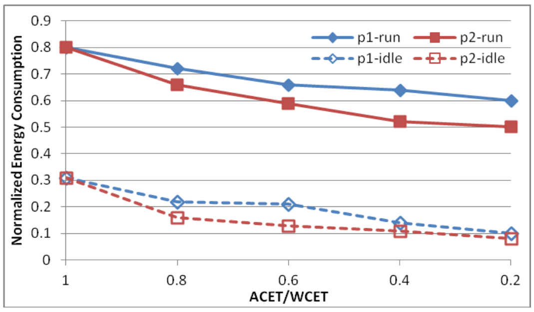


Fig. 10. Energy consumption of different slack time

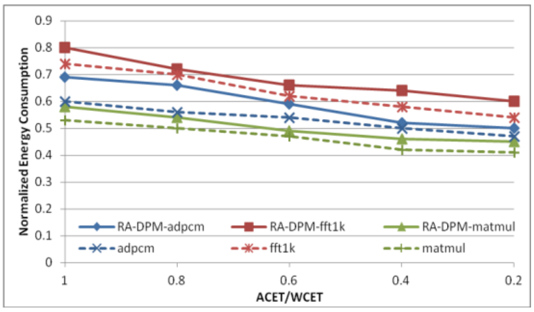


Fig. 11. Energy consumption comparison

As it is shown in **Fig. 11**, we implement another DVFS-based reliability-aware energy efficiency method RA-DPM [19], and perform comparison with our proposed method on *adpcm*, *fft1k* and *matmul* programs. From the normalized energy consumption results, we can see that these 3 programs are showed with different energy consumption level. That is because they have different complexity and execution time. However, they give the same decrease trend when the ratio of ACET/WCET decreases. And our method always output a better performance with lower normalized energy consumption on each programs.

In order to evaluate the effectiveness and reliability of our proposed method, we implement our proposed task scheduling to simulate the data processing in sensor nodes of WBAN. The simulation is developed in Java. As it is shown in **Fig. 12**, we have a Sensor Event Generator to simulate a random generated sensor event and then send sensor event to sensor nodes, which are considered to be equipped on human body. Both of these two sensors can receive sensor event from generator by *sensing_in* port, while it can also receive neighbourhood event through *neighbor_in* port. Then all the collected sensor events are transmitted to the Personal Device node and finally send notification to Medical Server or Medical Care Person.

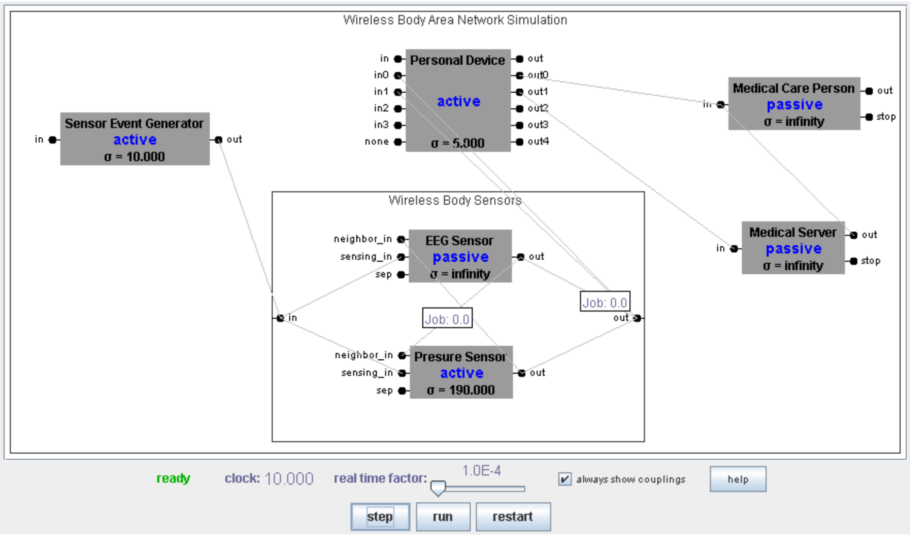


Fig. 12. Usage of Longer Slack Time

To evaluate the effectiveness of proposed method, we generate sensor event as a job with a start time and a hard deadline, then we propose to scale frequency in EEG Sensor and Pressure Sensor. The count of generated sensor event varies from 10 to 2000 with a random hard deadline [10-100ms]. Each sensor event (job) is randomly assigned a minimum processing time [0-1ms]. As it is shown in **Fig. 13**, the frequency of processing unit start to scale as the job count increased. There is nearly 70% of the generated sensor event need to be scaled to processed, which shows the effectiveness of our proposed method.

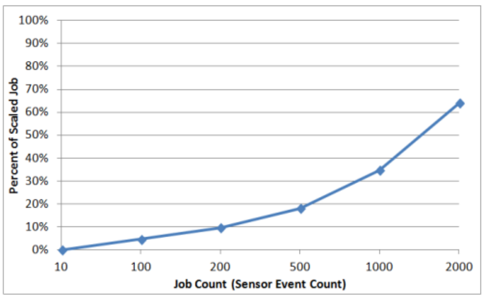


Fig. 13. Percent of Scaled Sensor Event

6. Conclusion

Potential applications with Wireless Body Area Network techniques including health care, athlete monitoring and soldier surveillance in ubiquitous environment are becoming popular recently. In this study, we have reviewed the existing research in the area of energy efficient WBANs. We have provided an introduction to WBAN and then discussed the energy-aware concerns in four categories: *node computation*, *network communication*, *topology deployment* and *energy scavenging*. This study proposes a new attempt in DVFS-based dynamic power management method with consideration of slack time during task scheduling, and concludes with open research in WBANs. Finally, we evaluate the efficiency and effectiveness of our method with an existing work in a simulated environment.

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