# A Phone-Based E-Health System for OSAS And Its Energy Issue

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*Abstract*—**Obstructive Sleep Apnea Syndrome (OSAS) is a widespread sleep-disordered breathing disease, which leads to repetitive hypoxemia, hypercapnia and interruptions of the normal sleep pattern. Considering its severe negative impact on human health, long-term monitoring of OSAS is necessary. Current OSAS monitoring systems require patients to stay in the hospital overnight and need considerable wiring between human body and the system. In this work, we propose a smartphone-based, wireless e-health system designed for OSAS. Our design offers a portable system that enables anytime and anywhere monitoring. Our experiments and modeling show that energy efficiency is the major bottleneck for sustainable operations of this battery-driven system. On the solution side, we can make full use of the low-power mode of Bluetooth, which is proved to be the energy bottleneck. The lifetime of the resulting OSAS system would increase by more than 50%. Our ongoing work seeks to take a holistic approach to more energy-efficient system.**

***Keywords-OSAS; e-health; phone-based; portable; energy-efficient***

## I. INTRODUCTION

Obstructive Sleep Apnea Syndrome (OSAS) is the most common category of sleep-disordered breathing which is characterized by abnormal pauses in breathing or instances of abnormally low breathing during sleep [1]. It has a wide range distribution among people and affects at least 4% of middle-aged men and 2% of middle-aged women [2]. OSAS has a considerable influence on human body, resulting in repetitive hypoxemia, hypercapnia and interruptions of the normal sleep pattern [3]. As a result of the frequent arousals and inability to achieve or maintain the deeper stages of sleep, OSAS can lead to excessive daytime sleepiness, non-restorative sleep, automobile accidents, personality changes, decreased memory, erectile dysfunction (impotence), and depression. OSAS has also been linked to cardiovascular diseases [4] [5].

Because of the severe consequences it may result in, there should be careful observation and diagnosis for OSAS. The diagnosis of OSAS is based on the polysomnography (PSG) which records eleven channels of various bio-signals. To get an overnight PSG, a patient should stay in a specialized sleep laboratory for nights, with 22 wire attachments around him/her and be attended by the specialists [6], as shown in Fig. 1. This brings great discomfort to the patients and they could not sleep well during the night, not to mention that an OSAS patient needs to be monitored for weeks. The wire attachments should be taken good care of by the attended personnel in case they drop down during the monitoring. Besides, for those patients who live in rural areas, it costs much time and money to go to the hospitals in the urban areas frequently to do overnight sleep monitoring.

As a result, a portable home monitoring system available at anytime and anywhere is needed. In this paper, we come up with a phone-based e-health system designed specifically for OSAS. This system is made up of several parts as follows: two sensor nodes to sample the necessary vital signs (namely the $SpO_2$ and the ECG indexes), a micro-control unit(MCU) to do data preprocessing, a smart phone to do diagnosis and a backend server to offer more sophisticated medical care services. The wireless connection keeps the patients away from the trouble of having to be still during the monitoring. This system could be able to work at anytime and anywhere such as the bedroom or the countryside where PC or laptop is not available. With such a system, patients could monitor their physical indexes in a more comfortable and less expensive way. This approach can make the long-term monitoring sustainable.

New challenges come along nevertheless. Reliability, real-time, portability and energy efficiency are the requisites for such an e-health system. Among them, energy efficiency is a big issue because limited battery capacity and high power consumption would make the system less applicable. In an OSAS home monitoring scenario, a patient should be monitored for nights, thus the frequent battery-charging will have a negative impact on the user's experience. So how to make such a system energy-efficient is a big challenge for us.

Fig. 1 OSAS Monitoring Equipment in Hospital [21]

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We try to address this challenge by analyzing the energy issue in the phone-based OSAS e-health system that we proposed. The analysis would offer elaborate references to the future work in this field.

We make the following contributions in this paper:

1. We present the design and implementation of an energy-efficient phone-based e-health system specifically designed for OSAS.
2. We make a detailed analysis about the energy issue of the phone-based e-health system for OSAS.
3. We propose suggestions to the energy issue, and we increase the lifetime of the system by more than 50%.

To the best of our knowledge, we are among the first to present an energy-efficient phone-based e-health system for OSAS, make a detailed analysis and offer suggestions on the energy issue of such a system.

This paper is organized as follows. Section II reviews the related work. Section III gives an overview of the usage scenario of the system and presents our design. Section IV presents our system implementation. In Section V, we make a detailed analysis about the energy issue in this system and present suggestions to this issue. Section VI concludes this paper and shows the future work.

## II. RELATED WORK

As shown in Fig. 1, the current OSAS system in the hospital is a cable monitoring system, having 11 channels and 22 wire attachments [6]. Patients should stay in hospital overnight with equipments and wires around, which would make the patients uncomfortable. In addition, it is also inconvenient for the patients who live in the rural areas to go to big hospitals to do long-term health monitoring.

An amount of research literate in the study of wireless homecare monitoring system and several wearable sensor-based health monitoring system architectures are proposed. [9-12] presented a phone-centric platform for personal health monitoring, in which a set of physiological sensors were wirelessly connected via Bluetooth to a cell phone. The phone stored, transmitted and analyzed the physiological data, and presented it to the user in an intelligible way. These systems could not be used directly in the OSAS scenario. As for OSAS, [8] and [13] came up with a similar system architecture compared with us, in which the phone could establish secure communication to a remote server for diagnose assist using either Wi-Fi or cellular 3G connectivity. However, [8] only used $SpO_2$ sensor while [13] only used ECG sensor. What's more, all the work listed above did not take energy efficiency into great consideration which would make the whole system get into power starvation.

Some of the research focused on the energy issue. [14] came up with a method to solve the energy issue by designing a new energy-efficient MAC protocol which was difficult to realize and inflexible for various sensor nodes. [15] presented a design of Wireless Body Sensor Network platform to tackle the challenges in cost, energy efficiency and did a first-step energy profiling. However, their systems are less general for OSAS. At the same time, their profiling results are not detailed enough for further discussion and design for an energy-efficient system.

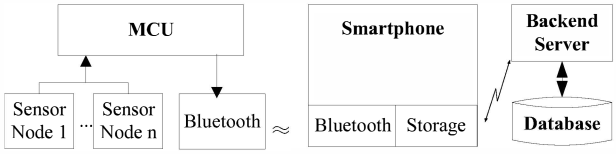

Fig. 2 System Architecture of OSAS e-health System

Our e-health system for OSAS focuses on energy efficiency and we present a detailed analysis of the system energy consumption. We also give some suggestions on the energy issue. All the above are vital to further research of energy-efficient e-health system.

## III. USEAGE SCENARIOS AND SYSTEM ARCHITECURE

### A. Usage Scenarios for OSAS e-health System

The phone-based e-health system for OSAS should be used at anytime and anywhere. The usage scenarios are no longer confined to the specialized laborites in big hospitals and a small scope of movement.

The physical index data got from the user are real-time dealt with by the MCU and the smart phone. Users could see some diagnosis results from the phone's screen. Such a scenario offers users more flexibility as they can use the system where they want to, whether in their bedroom or in the countryside where PC or laptop is not available. A further detailed diagnosis could be done if the wireless connection between the phone and the backend server is available. What's more, users can build their own individual OSAS records by uploading and saving the diagnosis results in the server.

### B. System Architecture

The usage scenarios motivate us to design a portable phone-based e-health system for OSAS monitoring.

As illustrated in Fig. 2, the system architecture of the phone-based OSAS monitoring system consists of five certain components, namely sensor nodes, MCU, Bluetooth module, a smart phone as the centralized controller and a backend server for storage and further detailed diagnosis.

In OSAS monitoring and diagnosis, the user's vital signs, motor activity and other health indicators should be collected by some certain sensors, such as EEG, ECG, EKG, $SpO_2$, blood pressure sensors, etc [18].We choose ECG and $SpO_2$ vital signs as diagnostic code, as recommended in [7], thus two sensors are used in our monitoring system.

The MCU is indispensible in our energy-efficient OSAS homecare system. The raw data from the sensor should be carefully dealt with, e.g. signal denoising and encoding (sometimes AD conversion is needed if the sensors do not offer such functionality). Although such computation can be put on to the smart phone too, our early-stage experiment has proved that with the same work load, the MCU could last for more than 20 hours, while the smart phone could only last for 6 hours, so we should consider to put more computations to MCU if it could bear them. We choose MCU as the processing unit for its light weight, low power consumption and easy getting start with. Besides, considering the requirements for computation, our system does not need to use a more powerful device than MCU such as a PC, etc.

The smart phone is the centralized controller of our system. The MCU continuously transmits the preprocessed data to the smart phone via Bluetooth, and the phone does more complex computation for diagnosis. The main functionality of the smart phone is to do complex computation such as feature extraction and classification, as well as providing the gateway connectivity to the remote server. The reasons why we choose a smart phone as the center of the system are as follows. The increasingly powerful functionality of smart phone makes it able to bury the burden of complex computation and it could offer the users a friendly interactive interface. It offers Bluetooth and Wi-Fi configuration interfaces which make the communication between different modules easy to realize. If the user changes his/her phone, the only thing to do is to download the software to the new phone which also supports the general communication protocol. Compared to PC or laptop, it is much lighter and easy to carry with. Besides, in the rural areas or the bedroom where PC or laptop is not available, smart phone is a better choice.

The communication protocol used between MCU and the smart phone can be based on Bluetooth, ZigBee, Wi-Fi or other self-defined protocols. The former three choices are more general and much easier to implement. As in our system, we choose Bluetooth. As [17] points out, the max data rate of Bluetooth, ZigBee and Wi-Fi are 0.72*Mbit/s*, 0.25*Mbit/s* and 54*Mbit/s* respectively while current sleep monitoring system utilized in hospital uses serial port to transmit data at a maximum speed of 0.1152*Mbit/s*. On condition of their all satisfying the requirement for data rate, to select the most energy efficient protocol is a wise choice. As [17] illustrated, in scenarios like mobile devices or battery-driven sensor networks, Bluetooth and ZigBee consume less power than Wi-Fi. However, ZigBee is also not a proper choice because most current mobile devices do not provide ZigBee configuration interface.

The backend server is used for further detailed diagnosis from the specialists. Users can even build their own individual OSAS records by uploading and saving the diagnosis results in the server.

## IV. IMPLEMENTATION

In this section, we present our early step implementation of the phone-based e-health system for OSAS.

As shown in Fig. 3, we chose $SpO_2$ and ECG sensors for data sampling. The one lead ECG sensor for monitoring heart activity is off-the-shelf, working at a sampling rate of 250*Hz* while the $SpO_2$ sensor for monitoring degree of blood oxygen saturation samples at 60*Hz*. To design a possibly small and portable system, we chose Arduino Pro Mini MCU because of its small volume. The phone we use is Samsung I9100 with an android OS and we use a GC-02 Bluetooth. The whole system is powered by a 3.3*V* battery.

Table I shows the detailed information about each component in our system.

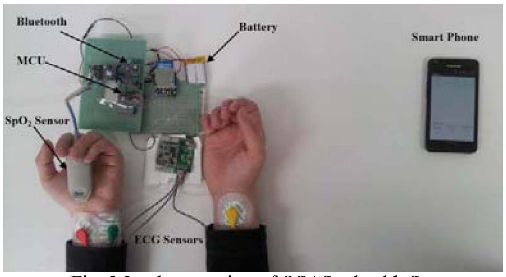

Fig. 3 Implementation of OSAS e-health System

TABLE I. SYSTEM COMPONENTS

| Module | | Type |
|---|---|---|
| Frontend | MCU | Arduino Pro Mini |
| | Bluetooth | GC-02 from Nanjing Guochun Tech Inc. |
| | $SpO_2$ Sensors | 60Hz sampling rate |
| | ECG Sensor | One-Lead, 250Hz sampling rate |
| | Battery | 1200mAh Li Battery |
| Smart Phone | | I9100 with Android OS 2.3.4 |
| Backend Server | | PC |

TABLE II. POWER CONSUMPTION OF EACH MODULE

| Module | State | Power Consumption (*mW*) |
|---|---|---|
| MCU | Active | 29.16 |
| Bluetooth module | Idle | 19.80 |
| | Active | 105.4 |
| Sensor | Active | 53.16 |
| Frontend Total | 5m Distance | 187.7 |

## V. ENERGY ISSUE AND ANALYSIS

In order to offer more convenience and flexibility, the system we design is battery-driven, thus energy efficiency should be a rather critical issue. The power consumption of the design must be low since frequent battery-charging will have a negative impact on the user's experience.

We firstly conducted a series of experiments to attain the power consumption of the frontend. The device we use for measurement is Monsoon FTA22D meter [20]. The distance from the Bluetooth module to smart phone is 5m, presenting the most common usage scenario when a patient sleep in the bedroom with a mobile phone near his/her bed.

As shown in Table II, the average power consumption of the total frontend is 187.7*mW* which means the frontend of the system consumes about 676*J* per hour and consequently, it can function for about 21*h* if the battery capacity is 1200*mAh* (the capacity of a normal battery for the portable device). In the OSAS scenario, it can last for only 2 nights which is obviously not satisfying. It is worth noting that the Bluetooth module consumes nearly 60% of the total power, and as a result, we give a high priority to the energy optimization of the Bluetooth module.

To make the solution applicable to most common Bluetooth devices, we rely on the high-level optimization and have not considered changing the Bluetooth stack firmware and designing a new energy-efficient protocol. We can notice in Table II that there are two basic modes for the Bluetooth module, namely, active and idle. The independent Bluetooth module in our system consumes 19.8*mW* when in idle mode while 105.4*mW* in active mode. The power consumption of the idle node is relatively small, of which we can make full use to reduce the total power system consumes.

Besides, according to [15] and our experiment result, due to various complicated reasons, the Bluetooth module inside the mobile phone does not change its power consumption between idle state and active state. Thus we did not take much consideration on the Bluetooth module inside the mobile phone.

Fig. 4 shows the power profiling results of the Bluetooth module in our system. After the Bluetooth module establishes connection with the phone, it would remain in active state which consumes more power unless it is forced to go into the idle state. The module in the idle mode should go to the active state through the connecting state.

In order to reduce the power consumption, we force the Bluetooth module to enter into idle state periodically. However, the MCU is indeed receiving data at the speed of sample rate continuously. As a result, there must be some extra memory in MCU to buffer the received data.

We built a detailed model to analyze the relationship among idle time, total power of the Bluetooth and the buffer memory of MCU.

The symbol definition is as follows. $P_{idle}$, $P_{connecting}$ and $P_{active}$ mean the power of Bluetooth in *idle, connecting* and *active* state respectively. $t_{idle}$, $t_{connecting}$ and $t_{transmitting}$ mean the period of time in each Bluetooth state respectively. $B$ is the baud rate between MCU and Bluetooth, $S_R$ is the sampling rate of sensors, and $N$ means the buffer storage of MCU.

The average power consumption of Bluetooth in *normal* condition is $\overline{P}_N$. It can be approximated to be $P_{active}$ as the system enters into the connecting state only once before it remains in the active state for transmitting data continuously. So we have

$$\overline{P}_N \approx P_{active} \tag{1}$$

The average power consumption of Bluetooth is $\overline{P}_{ISP}$ when it enters *ISP* condition (*idle state periodically*), calculated as follows

$$\overline{P}_{ISP} = \frac{P_{idle} \cdot t_{idle} + P_{connecting} \cdot t_{connecting} + P_{active} \cdot t_{transmitting}}{t_{idle} + t_{connecting} + t_{transmitting}} \tag{2}$$

In *ISP* condition, when the Bluetooth is not transmitting, there should be some buffer memory in MCU for sampling data storage, its capacity is:

$$N = \left(t_{idle} + t_{connecting} + t_{transmitting}\right) \cdot S_R \tag{3}$$

And we also have:

$$t_{transmitting} = \frac{N}{B} \tag{4}$$

From (3) and (4), we can have:

$$N = \frac{B \cdot S_R}{B - S_R}\left(t_{idle} + t_{connecting}\right) \tag{5}$$

Equation (6) then comes from (2) and (5):

$$\overline{P}_{ISP} = \frac{P_{active} \cdot S_R}{B} + \frac{\left(B - S_R\right) \cdot \left(P_{idle} \cdot t_{idle} + P_{connecting} \cdot t_{connecting}\right)}{B \cdot \left(t_{idle} + t_{connecting}\right)} \tag{6}$$

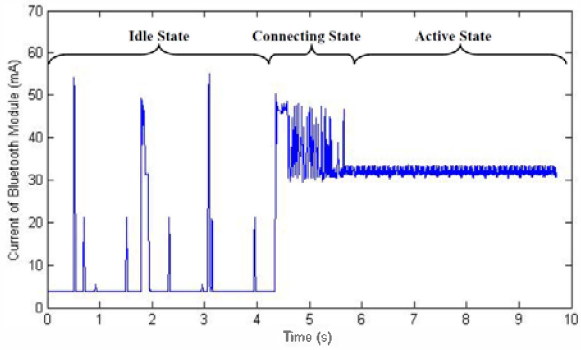


Fig. 4 Power Profiling of Bluetooth Module (x label for time clock, while y label for its instantaneous current)

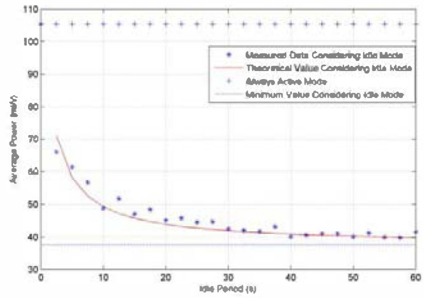


Fig. 5 Average Power of Bluetooth Module with Different Idle Periods (x label for idle period of the Bluetooth module, while y label for its average power)

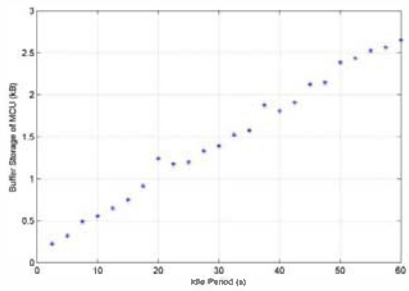


Fig. 6 Buffer Storage of MCU in Different Idle Periods of Bluetooth Module (x label for idle period of the Bluetooth module, while y label for buffer storage of MCU)

Fig. 5 shows the relationship between the average power and the idle period and Fig.6 shows that between buffer memory of MCU and the idle period.

We can notice that, with the increase of idle period, the average power consumption of the Bluetooth module is decreased and the buffer memory keeps increasing. However, the curve shown in Fig. 5 is a hyperbolic curve with an asymptote, while the curve in Fig.6 is like a straight line.

From Fig. 5 and Fig. 6, we can see obviously that when the idle period is beyond certain point, say 30s, the energy saving cannot compensate for the cost paid for extra buffer memory of the MCU. Considering the diagnosis timing requirement, an interval of 30 seconds is acceptable in OSAS [19]. As a result, we select 30s as the idle period.

The power consumption of the optimized Bluetooth module is 42.5*mW*, while that of a Bluetooth module in normal condition is 105.4*mW*. The energy consumption of the Bluetooth module is decreased by nearly 60%, with this calculation, the life time of the frontend including the sensor nodes, MCU and the Bluetooth module would be increased by 11 hours (32 hours' life time which means 4 nights for the optimized system).

According to the discussions above, we offer the following suggestions for the energy issue.

1. To save power, the Bluetooth module should be periodically forced into the idle mode and there should be extra memory to buffer the received data so as not to lose data used in the diagnosis of OSAS during the idle period.

2. We should choose longer idle time to gain more power saving. However, beyond certain point, the energy saving cannot compensate for the cost paid for extra buffer memory of the MCU. We should balance between these two metrics with a consideration on OSAS diagnosis timing.

## VI. CONCLUSION AND FUTURE WORK

In this paper, we present a phone-based e-health system specifically designed for OSAS and come up with a detailed analysis about the energy issue of the system.

Based on a series of experiments we conducted, we have found the bottleneck of the system- Bluetooth and optimized the energy consumption by making it into idle mode periodically. The results have shown that energy consumption does decrease by a large percentage. Within a certain range, the longer the idle period, the more energy it saves. However, the price for energy savings is the memory storage of the MCU. As a result, we should balance between these two metrics.

The improved system can last for 32 hours (i.e., 4 nights in our scenario), an 11-hour increase compared with the previous design. However, this is still not satisfactory and a more effective solution to the energy problem needs to be found. Some techniques including adaptive sampling, feature selection, compression, encoding and load-balancing scheduling might be used to reduce the energy consumption of the whole system. We would explore a holistic energy-efficient approach in the future work.

## ACKNOWLEDGMENT

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