Data Compression in Wireless Sensor Nodes Used for Data Acquisition of Slowly Changing Digital Events

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Abstract: Energy conservation is an important consideration in Wireless Multimedia Networks (WSNs) powered by batteries. Energy optimization directly leads to increased lifetime of a WSN. In this paper, we consider a class of WSNs deployed to sense digital events and transmit the state values to a sink node. In these WSNs, considerable minimization of energy consumed can be achieved by reducing the number of bits transmitted to convey the same digital signal values. We show that energy required to transmit digital values can be minimized by adopting simple compression schemes. It is shown that for digital signals with very long runs of 1s or 0s considerable energy efficiency can be achieved.

Keywords: WSN, Energy Efficiency, Sensor Node, Digital Signal

I. INTRODUCTION

Wireless Sensor Networks (WSNs) find applications in many areas such as military, space exploration, environmental studies etc for sensing and transmitting of both analog and digital signals. As a general requirement, WSNs must last longer by conserving energy as much as possible. A typical wireless sensor node employed for sensing digital events mainly consists of sensor electronics with sensor(s), a micro-processing unit and radio module as shown in Fig. 1. To conserve energy, the radio and other electronics subsystems are activated from sleep state only when data is to be transmitted, and are reverted to sleep state after transmission. Pawar et. al. [1] have presented an empirical energy consumption modeling of a wireless sensor node by considering the current consumed by the radio during different states of operation. As shown by them, the radio module consumes the maximum amount of energy while transmitting data to other nodes. Therefore, to minimize energy consumption and consequently extend the life of a WSN, it is desirable to minimize the number of bits of transmission required for conveying the information relevant to the context of application of the WSN.

The energy consumption by the radio during transmission can be expressed [1] as:

\[ E = T(b) * I_t * V_s \]  \hspace{1cm} (1)

where,

- \( T(b) \): Transmission duration for \( b \) bits,
- \( I_t \): Current drawn by the radio , and
- \( V_s \): Nominal battery voltage.

Following the IEEE 502.15.4 which has 31bytes of overhead for each transmission by the wireless node, \( T(b) \) is given by the following equation:

\[ T(b) = 8*(31+B)/R_b \]  \hspace{1cm} (2)

where,

- \( B \): the number of bytes of data to be transmitted, and
- \( R_b \): bit rate in bits per second.

Therefore, energy consumption for transmissions can be minimized if the information to be conveyed is compressed into as few bits as possible [2]. As shown in [2], for a special class of WSNs which are used for capturing sampled analog data from slowly varying parameters, it is possible to reduce the number of bits per sample from the full length to achieve energy
minimization. This method involves a form of data compression of digitized analog values. In this paper, we extend the work in [2] to the case of WSNs required to monitor digital events and convey the information to the sink node. We show that, as compared to time-stamping of event transitions, if compressed data relative to the first instant of transmission is done, considerable reduction in energy required for transmission can be achieved. In the following sections, details of the proposed schemes for digital data compression and results of simulation are presented.

II. RELATED BACKGROUND

As already mentioned, the most immediate background work related to the subject matter of this paper is the energy minimization approaches presented in [2]. This work carried out by one of the authors of the current paper focuses only on slowly varying analog signals. But as data acquisition applications may also involve digital signals, we have taken up the case of digital input signals in this paper.

Both the area of research of this paper and [2] fall under the category of methods aimed at data compression in WSN for the purpose of minimizing volume of transmitted data by a node and thus minimize its energy consumption. Anastasi et.al have given in [3] a very exhaustive and useful survey of energy conservation methods applicable in WSNs in general.

They have brought out energy efficient data acquisition as an area not explored by many researchers.

The subject matter of our paper relates to data compression which can be done in several ways (e.g., [4]-[6]). As nodes used in data acquisition applications are often required to be low cost and have very limited processing and memory resources, many of the general purpose data compression methods are difficult to be adopted for implementation. The proposed data compression schemes of this paper are special cases of data compression involving raw digital data obtained from sensors attached to the nodes.

III. PROPOSED SCHEMES

In the proposed schemes for data compression, instead of sending time stamp for every data transition, the periods of 1s or 0s are codified using less number of bits than required for time stamps. The simplistic scheme called here as the Straight Forward Scheme (SFS) is presented first followed by three better schemes proposed in this paper.

Straight-Forward Scheme (SFS):

Consider the part of digital signal shown in Fig. 2. A sensor node acquires a signal such as this by sampling sensor input at regular period of time $t_0$. For reconstruction of this signal, the sensor node has to transmit the time stamp (24 bits to represent day, hour, minute, and second) and whether the transition is a 0-to-1 or a 1-to-0, which requires an additional bit. If we consider a digital event consisting of 128 periods with alternating 1s and 0s, the number of bits required to be transmitted by a sensor node is 3225 (25 bits per transition and 129 transitions). As mentioned earlier, we can minimize the number bits to be transmitted and consequently the energy consumed for transmission by codifying time period $T$ of continuous 1s or 0s. The compression schemes based on this are discussed below. For comparing the different schemes with the SFS, the maximum time period for which a 1 or a 0 exists is assumed to be $255*t_0$ so that only 8 bits are enough to quantify $T$.

![Fig. 2 A portion of digital input signal](image)

Scheme 1:

In this scheme, the durations of 1s and 0s are considered separately, and expressed in terms of the sampling duration $t_0$ as the basic time unit. The time stamp at the start of sequence is transmitted. To distinguish the bits used for time stamp and for time durations, the formats shown in Fig 3 are adopted.

![Fig. 3 Bit formats for Scheme 1](image)

With this coding, it can be shown that the number of bits required to transmit a sequence of 1s and 0s is

$$N_b = 24 + \sum \left\lfloor \frac{L_i}{2^m-1} \right\rfloor + 1 \times (m+2)$$  \hspace{1cm} (1)

where,

$L_i$ = length of the $i^{th}$ duration (1 or 0) and $i= 1$ to 128.
Scheme 2:

In Scheme 1, the number bits ‘m’ allotted for representing the time periods is fixed. This is useful if the expected variation of the digital events is such that the 1 or 0 periods vary around a certain average value that can be represented with m-bits in most cases. However, there could be situations where the periods of 1s and 0s may be spread over a logarithmic range. In such cases, the number of bits required to transmit becomes enormous and purpose of energy minimization is defeated. However, the problem can be addressed by allowing variable number of bits as per the format shown in Fig. 4.

Fig. 4 Bit formats for Scheme 2

In his scheme, the first 3 bits indicate that time duration of 1s or 0s is represented in variable bits format and whether the next two fields pertain to 1s or 0s. The second field of 4 bits gives the number of bits k (2 to 15) that will be used to code the time duration. The last field gives the actual k bits that represent the 1 or 0 periods. Therefore, the number of bits required for each 1 or 0 period varies from 7+2 to 7+15. The total number of bits required as per this scheme is given as

\[ N_b = 24 + \sum(7+k_i) \]  

where, \(m\) = number of bits required of half period representation, and

\[ k_i = \text{number of bits required to represent the period } T_{DB}. \]

IV. SIMULATION AND RESULTS

The proposed schemes were simulated for a single node by generating random samples of data and numbers of bits required for each case were compared with the SFS case. The digital input signal considered in each case was tweaked to ensure that the situation for which the case applies is encountered in the simulation. The results for each case are presented below.

Simulation for Scheme 1:

The digital signal considered in this case is a 128 period run of 1s and 0s. The duration of each period was set as a random time in the range 50tS to 200tS. As 128 bit transitions are considered, the number of bits required for the SFS scheme is 3225 as mentioned earlier. The number of bits required for Scheme 1 is given by Eqn.(1) with \(L_i\) values set by the random numbers generated in the simulation run. Fig. 6 shows the results of simulation. As seen from this result, for \(m=8\), 7, and 6, reduction in transmitted bits is achieved. For \(m\) values lower than 5, the overhead bits required at the beginning of each transmission fields and numbers of fields required are so large that transmitting time stamps is more energy efficient.

Fig. 6 Number of bits for Scheme 1
Simulation for Scheme 2:

In this scheme, the case of very long periods of 1s and 0s need to be simulated. The digital input simulated has 1 or 0 durations ranging from $t_S$ to 200$t_S$ for the first 16 periods of the 128-period interval, and gradually increasing over the next 112 periods with the last period having 1 or 0 durations ranging from 50000$t_S$ to 60000$t_S$. The results obtained with simulation and by using Eqn. (2) are shown in Fig. 7. It is clear that in this case, Scheme 2 is far superior to Scheme 1 with fixed 8 bits.

Simulation for Scheme 3:

In this case, the digital input considered is a square wave with 128 cycles with each cycle with randomly assigned duty cycles. The period of each cycle is set as 255 $t_S$. Results are obtained by using Eqn. (3) with $m=8$, and $k_i$ values set by the simulation run. Fig. 8 shows the percentage of reduction in number of transmitted bits and hence energy consumed for 10 simulation runs. As seen from the 10 runs of simulation, about 8% of reduction in energy consumed can be achieved by this scheme.

The percentages of energy reduction that can result by applying the three schemes as compared with the SFS scheme are shown in Table I. These values are only indicative of the range of energy savings possible. In actual applications, the energy savings depend upon type of digital inputs encountered and the choice of scheme applied by the transmission bit stream algorithm.

V. CONCLUSION

In this paper, we have extended the work in [2] to the case of WSNs required to monitor digital events and convey the information to the sink node. The three schemes presented, involve transmitting time stamp once at the beginning of a transmission session and thereafter transmitting bits organized in well-defined fields that capture the time duration of successive runs of 1s and 0s. The schemes achieve reduction in number of bits required to be transmitted in compassion to the straight forward scheme (SFS). From the simulation results we can see that even though Scheme 3 is an alternative approach, it does not result in higher energy savings as compared to the other two schemes. While Scheme 1 is much better than Scheme 2 for digital input signal with short to medium run of 1s or 0s, it fails to minimize the number of bits for transmission when very long runs of 1s or 0s are encountered. Therefore, in practice, both Schemes 1 and 2 must be used by a wireless sensor node depending on the bit stream at hand that needs to be transmitted.

The subject matter of this paper along with the methods presented in [2] for analog signal data when adopted by the nodes of a WSN can considerably improve their life time.

A further line of research planned for future is to explore the possibility of arranging blocks of 1s and 0s as matrices and transmitting matrix dimensions.

TABLE I

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Percentage reduction of energy for transmission</th>
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<tbody>
<tr>
<td>m=8</td>
<td>59.56589</td>
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<tr>
<td>m=7</td>
<td>46.7907</td>
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<tr>
<td>m=6</td>
<td>23.84496</td>
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<td></td>
<td>19.6625</td>
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<td>7.969</td>
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REFERENCES


