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A Functional Approach for Wireless Sensor Node Energy Consumption Modeling

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Abstract: Embedded applications in the field of wireless sensor nodes are becoming more and more sensitive to energy consumption. This latter actually depends on the autonomy of the application, but also on its performance. One must take into account the constraints of energy consumption when specifying and designing an application. In this document, instead of considering applications, we raise the level of abstraction to study various functions. We present a classification of possible functions in wireless sensor nodes. Then, we propose a functional approach modeling in order to get a more accurate estimate in term of energy consumption for each function. Input and output parameters of the functions are investigated to identify the relationships between them. The final goal of this work is to provide an efficient energy consumption optimization tool for wireless sensor nodes designers.

Keywords: *wireless sensor nodes, energy modelization, power consumption.*

1 Introduction

Works on energy consumption optimization in sensor nodes often seek optimization of communication strategies [1, 2], routing techniques [3, 4], network topologies [5, 6] or on hardware devices [7]. In this document, we work on the global set of functions and the hardware devices are not used but just conceived to be in the functions. Our study is therefore placed on a higher level of abstraction, where we choose to create links between the different functions to establish a functional model of the node. Hence, we rather focus on function characteristics and the links between them. Our motivation is to provide the energy consumption in a function, as a first step, and to accurately identify its input parameters, which are often given by other functions, and its output parameters. After reviewing the state of the art about optimization strategies, we give the plan of the document as following : first, our starting point is defined as a classical low level of abstraction architecture model of node. Then, we propose a functional approach modeling. And after, an energy modeling of a simple node is taken. And Finally, we conclude and draw future works directions.

2 Sensor node energy modeling

A sensor node is a set of energy-independent electronic devices. Each of them includes a sensor and a radio module that can receive data from other nodes and transmit its own wirelessly. There are several ways to model a node, depending on the objectives of the research. Our starting point is a classic modeling, a very classical low level of abstraction architecture model of a node. This model takes only the various hardware and software parts of the node into consideration. Starting from that model, we can identify the different functions in each node block. Then gradually, we raised to a relatively high level of abstraction that only considers the main functions in the node.

3 Functional Modeling

We have chosen as an example three main functions inside a sensor node namely : acquisition function, memory function and transmission function. The acquisition function provides data captured and can operate on two operation modes : the event mode and the periodical mode. The memory function stores these data from the acquisition function, and provide it to the transmission function. In order to emphasize the specific power consumption for each of these functions, we need to identify their characteristics. Then, it seems necessary to propose a node functions classification.

3.1 Classification of mode functions

There are various manner to classify nodes, but we are interested in distinguish them according to their activation mode and their data management mode. Activation mode of a function can be multiple, namely a function can be an event active function, an input state active function or a permanently active function. The event active function is based on emergence of specific events. While, permanently active function still be active even if a specific event appears or not. Then, the input state function is based of the input characteristics of the function. We are also interested on its data management mode, namely a function can be a data transfer function, a data storage function, a data processing function, control/decision management function. The data transfer function provide high energy messages because the function processes raw data flows. While, control/decision function provide low energy messages because the function processes only control signals. The data storage function provide energy which depends on the used technologies. The data processing provide energy which depends on the algorithms complexity. Recalling the examples of node functions above, we can then characterize them according to the proposed classification modes. This is what we show in the table bellow.

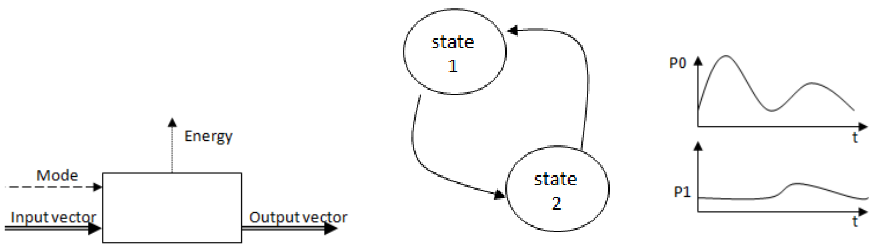
Function	Activation mode	Data management mode
Acquisition	Event sensible	Data transfer
Memory	Permanently active	Data storage
Transmission	Input state sensible	Data transfer

Table 1: Functions classification

3.2 Node function modeling

Depending on the purpose of the function, the power consumption can be high or low, and the function can be permanently active, only periodically active or activated by event. In any case, in order to modelize the power consumption, we need almost three different views. The model consists in three views : A block function representation, a behavior description, a set of power profiles.

The block function representation view allows to connect functions to each other into a block diagram schematic. The behavior description don't need to be very accurate, but aims at describing the inner state of the function, and the transition conditions between the states. The set of power profiles provide the average power consumption versus time for any inner states adopted by the function. It can be obtained by measurement or estimated from datasheet components.



(a) Block representation (b) Inner State behavior (c) Profiles power set

Figure 1: Function model definition

For any function, some inputs and outputs have to be defined. First of all, a Mode input is required in order to tune the way the function is working, which is the governing element of the power consumption. This intern behavior of the function can be characterized by a set of inner states associated to a set of power consumption profiles. Behavior of the function is also affected by some input data which may play a role in the power consumption of the function. This is why an Input vector needs to be added in the block representation. Likewise, depending on the function itself, an Output vector is required to represent some data productions of the function which are obviously a source of energy dissipation too. As a result, an evaluation of the consumed energy by the function can be obtained by integrating power consumption profiles along the time axis. Given that a function behavior is described by its inner states, the choice of the integrated power profiles is ruled by the inner state behavior description of the function.

4 Energy modeling of a simple node

Let's take a simple example of use case : node captures data at each occurrence of a specific event, and the data will be stored in memory before being transmitted to the transmitter. So, we recover the three main functions namely : acquisition function, memory function and transmission function.

The figure 3 below shows the relationship between main functions inside a sensor node. Some functions rely on information coming from other functions, or can provide them information.

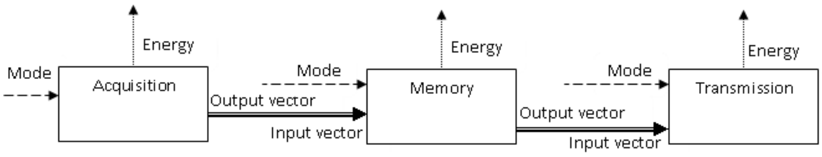


Figure 2: Functional model

As we can see in the TABLE I, the acquisition function is classified as an event sensible and data transfer function. We modeled this function with two inner states : ACTIVE and SLEEP which will be associated to profiles of power consumption. Switching from one profile to another depends on the event sensible activation mode. This mode is based on emergence of specific events. The function shall be active depending on this event. (e.g. a motion sensor). Otherwise the function remains in its sleep inner state. The input/output vector depends on the data management mode. The acquisition function is a data transfer function. One can notice that all functions can not necessarily process the same data types. The memory function is a buffer memory function, it has three operatives inner states, which will be associated to a set of three power consumption regimes, WRITE_BUFFER state, READ_BUFFER state and IDLE state. However, this function is classified as permanently active and a data storage function.
The transmission has at least two power consumption profiles : active and sleep. Switching from one profile to another depends on the input state activation mode. This function is classified as data transfer function.

The classification of mode functions and the node function modeling allowed us to define the behavior of each node. We will see then the behavior of each function in our model of simple node and we will describe it under an algorithm form.

Algorithm 1 Acquisition function behavior

```
while TRUE do
   profile = SLEEP;
   sense(event);
   if event=TRUE then
      profile = ACTIVE;
      transfer(data);
   end if
end while
```

Algorithm 2 Memory function behavior

```
buffer_full=FALSE;
while TRUE do
   while receive(data)=TRUE do
      if buffer_full = FALSE then
         WRITE_BUFFER(data) ⇐ Input_vector;
      end if
   end while
   if buffer_full = TRUE then
      READ_BUFFER(data) ⇒ Output_vector;
      initialize(buffer);
   end if
   IDLE();
end while
```

Algorithm 3 Transmission function behavior

```
while TRUE do
    profile = SLEEP;
    while input_state = TRUE do
        profile = ACTIVE;
        transfer(data);
    end while
end while
```

For any function n, the inner states in the behavior description are characterized by the profiles of power consumption $P_{n,i}(t)$. Those profiles, each one associated to an inner state of the function, give the power consumption over the time and are not necessarily constant functions of time. The power consumption profile $P_n(t)$ of the function n can then be written as a linear combination of the profiles $P_{n,i}(t)$. Given an observation duration T, the energy consumed by the function n is $E_n = \int_T P_n(t)dt$. And finally, an evaluation of the overall consumed energy in the node is given by:

$$E = \sum_n \int_T P_n(t)dt$$

5 Conclusion

From the related work, we have been able to identify the main functions of the node, by specifying essential parameters which characterized the energy consumption in each function. The function characteristics depend on its classification. We have been able to modelize the main functions by identifying input and output parameters for every function, and foremost by linking them. A functional approach model of the node has enabled us to get a more accurate estimate in term of energy consumption for each function. From a general point of view, we have proposed a novel approach to modelize the node cross-layer on a high level of abstraction. The future works shall validate our model of the node by simulating it with SystemC, as well as improve and extend our model by considering the whole network.

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