Research on OPNET energy simulation application in wireless sensor network

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Abstract. Considering the problem of not providing energy model in OPNET, a modeling method in WSN is presented. First the modeling process of energy model and the way of its realization are analyzed. Then by introducing RM battery model with higher precision in describing the battery discharge, the energy model in OPNET is established. The results of simulation shows that the modeling method is valid and a better estimation of node lifetime can be achieved using RM model.

Keywords: WSN, OPNET, Modelling, battery model.

1. Introduction
WSN nodes usually use batteries as energy sources, and the limited energy makes WSN protocol to reduce energy consumption and extend network lifetime become an important research topic. At present, simulation is the main means of WSN protocol research. Using network simulation tools (such as OPNET [2], NS2 [3]) to realize energy model modeling is one of the preconditions of protocol simulation research. In the aspect of network simulation tools, OPNET has been widely used in the research of wireless network simulation because of its rich protocol model base and wireless transmission characteristics modeling, but it does not provide the energy model which affects the perfection of OPNET tools to a certain extent. In terms of energy model, the existing network simulation tools are either not provided or too simple (such as NS2 with linear model). The initial energy value is set for each node in NS2. When each node sends or receives a packet, a certain amount of energy is subtracted (the default value is 281.8mw). When the energy is exhausted, the node fails. However, as a node energy source, the battery shows nonlinear discharge characteristics due to the influence of rate capacity effect and recovery effect [4]. The introduction of accurate nonlinear model will make the energy modeling more reliable. Rakhmatov et al. (2001) derived a kind of battery model (RM) which can describe the non-linear discharge characteristics of lithium battery. On this basis, an algorithm of battery life estimation was given. Based on OPNET, this paper proposes a WSN energy modeling method, and further introduces a more accurate RM battery model to realize OPNET energy modeling and simulation.
2. OPNET energy modeling method

WSN nodes are generally composed of four units: wireless communication, processor, sensor and energy. The modeling problem of node energy unit can be transformed into the modeling problem of battery model, which is closely related to the working state of node and its conversion process. WSN nodes generally include four working states: sending, receiving, sensing and sleeping. The battery load (current) is different under different working conditions. The conversion process between the four States reflects the discharge process of the node battery, and then affects the battery life, that is, the node life. It is the premise of battery modeling to determine the working state of the node and its conversion process.

Based on OPNET, the modeling of battery model is divided into three processes: the determination of node working state, the real-time determination of node working state transition process and the implementation of programming with OPNET proto_C language.

(1) determination of node working state. The network protocol stack of the OPNET simulation model of a node is generally composed of application layer, network layer, MAC layer and physical layer. Each protocol layer corresponds to one or more OPNET process models. By introducing a new process between the MAC layer process and the physical layer process, the working state of the node can be determined. This process contains an energy model, which is responsible for directly forwarding the data frame received from MAC layer or physical layer down or up until the node fails. The working state of the node is determined by judging the data flow of the energy model process. Among them: from the process receiving the data frame of MAC layer to the full sending to physical layer, it is in the sending state; from the process receiving the data frame of physical layer to the full sending to MAC layer, it is in the receiving state; if there is no data frame in the non sleep state, it is in the sensing state; the sleep state is determined by MAC agreement.

(2) the real-time determination of node working state transition process. The energy process model not only needs to determine the working state of the node, but also needs to introduce a certain mechanism to determine the working state transition process in real time, and then determine the battery discharge process in real time. Firstly, a state variable state flag is introduced into the process of energy model. The state flag contains four constant values, STATE_TRAN, STATE_RECE, STATE_SENSE and STATE_SLEEP, which respectively represent the four working states of the node: sending, receiving, sensing and sleeping. In the process of simulation, if the working state of the node changes, the State Flag will change accordingly to ensure that the state flag is consistent with the working state of the node. Then, the state flag is sampled with the sampling frequency f, and the working state of the node at any sampling time is determined by judging the state_flag value. By recording the time stamp of sampling time and the working state of nodes at sampling time, the working state transition process of nodes can be determined in real time.

(3) programming with OPNET protocol language. Battery model is the key of energy modeling, its accuracy determines the reliability of energy model, so the battery model should be carefully selected. When the working state of the node is determined, the discharging process of the node battery is determined accordingly. Then, for the specific battery model, the process modeling of the energy model is realized by using proto_C language.

3. Energy modeling and simulation

RM battery model is selected as the battery model of this paper. Next, based on OPNET energy modeling method and real-time battery life estimation algorithm, the energy modeling and simulation method is studied.

If the maximum output capacity of the battery is \( \alpha \) and the compensation rate of the active carrier on the electrode surface is \( \beta \) (the larger the \( \beta \) value is, the better the discharge characteristic is), then the battery life \( L \) has the following relationship with the load current \( I(\tau) \):

\[
\int_0^L i(\tau)d\tau + 2\sum_{m=1}^\infty \int_0^L i(\tau)e^{-\beta m(L-\tau)}d\tau - \alpha = 0
\]  

(1)
If the step function is, the average load current in \([TK, TK + 1]\) time is \(I_K\), then the variable load current in \([0, t]\) time can be approximated by n-step function, that is, the constant load current of a certain width can be used to approximate the variable load current, then:

\[
i(t) \approx \sum_{k=0}^{N-1} I_k [U(t-t_k) - U(t-t_{k+1})]
\]

Substituting formula (2) into formula (1), we can further obtain:

\[
\sum_{k=1}^{N} 2I_{k-1} A(L_\alpha, t_k, t_{k-1}, \beta) - \alpha = 0
\]

Equation (3) is the mathematical model of RM battery for calculating battery life. Because it is not an explicit formula of battery life and load current, it is difficult to directly solve the battery life.

For this reason, Handy et al. put forward a real-time battery life estimation algorithm in [6], which provides the battery model with the battery load current value method at any simulation time through the simulation environment, and determines the battery discharge process at any time in real-time, so that the RM battery mathematical model can be integrated into the network simulation environment. Fig. 1 is a schematic diagram of the interaction process between the simulation environment and the battery model. The battery model obtains the load current \(l_{ts}\) and its time stamp \(t_{st}\) from the simulation environment according to a certain sampling frequency \(f\). If the LTS changes during the sampling process (for example, if \(LTS \neq ik-1, K\), the change times of the battery load current will be recorded), the changed value \(IK\) and its corresponding time stamp \((SK = TS - \Delta)\) will be inserted into the current array \(L_i\) and time stamp \(st\) respectively, and the battery discharge process from the beginning of simulation to the sampling time can be recorded by using \(L_i\), \(St\), \(l_{ts}\) and \(t_{st}\). Figure 1. Schematic diagram of interaction process

\[\text{Figure 1. Schematic diagram of interaction process}\]

The algorithm first defines the global variables \(L_i\), \(St\), \(\Delta\), \(K\) and \(\alpha\), \(\beta\), and then circularly executes the battery state judgment process: when the sampling time arrives, the load current value \(l_{ts}\) and its time stamp \(t_{st}\) are obtained from the simulation environment and transferred to the function discharge \((LTS, TS)\). The function first updates \(L_i\) and \(St\) according to the process shown in Figure 1, and then substitutes the parameters \(LTS, TS, L_i, St\) into the RM battery model for calculation from simulation The battery capacity consumption from the true start to the \(TS\) time; if the consumption value is less than \(\alpha\), it means the battery has not been exhausted, wait for the next sampling time to repeat the above process, otherwise it means the battery has been exhausted, and the battery life is the current simulation time.

### 3.1. OPNET modeling implementation

According to the requirements of real-time battery life estimation algorithm, the simulation environment needs to provide model parameters, i.e. battery load current \(l_{ts}\) and time stamp \(t_{st}\), according to a certain sampling frequency \(f\). As the battery load current value corresponds to the node working state, the real-time determination mechanism of the node working state transition process can be used to obtain the battery load current value at the sampling time by judging the node working state under the frequency...
f. The sampling time stamp can be obtained by OPNET core function OP SIM time (). Then, according to the real-time battery life estimation algorithm, the RM battery model is built by using proto_C, and then the energy model process is constructed. Figure 2 shows the OPNET process of the energy model, in which the finite state machine battery is used to implement the RM battery model.

![Image of OPNET process model](image)

**Figure 2.** Energy model process model

### 3.2. Simulation results

Next, the energy model is embedded into the node simulation model and a simple network simulation environment is built to verify the implementation of the energy modeling process and briefly analyze the performance of RM battery model. The network simulation environment and its parameters are as follows: there are two nodes, node 0 sends 1024bits packets to node 1 at the rate of 2packets / s, and the simulation time is 15s; the nodes have the same characteristics as mica motors : ATMEG aemega128l processor (active working current is 8Ma, inactive state is 15 μ a), CC1000 wireless transceiver (transmitting state working current is 27ma, Receiving state 10mA, sensing state 10 μ a, sleeping state 1 μ a) and AA alkaline battery. According to the data in literature 8, the battery parameters are α = 245910ma MS and β = 4034. Since most of the energy consumption of the node is consumed in the wireless communication unit, the load current in the working state is taken as it = 27ma, IR = ISE = 10mA, ISL = 1 μ a respectively. In fact, the parameters can be obtained by actual measurement.

![Image of simulation results](image)

(a) Load current                         (b) Partial enlarged view of ABCD area

**Figure 3.** The parameters can be obtained by actual measurement.

The load current of node 0 and its partial enlarged map collected in the simulation process. It can be seen that the energy model process can accurately detect the node working state and its changes and obtain the load current value, which shows that the node state determination mechanism and the real-time judgment mechanism of the node state transition process are feasible.

The recovery effect described by RM battery model can be seen. The recovery effect generally occurs in the transition period of battery load from higher value to lower value. When the node changes from the sending state to the sensing state, it can be seen that there is a certain degree of recovery of battery capacity, but no recovery occurs when the node changes from the sensing state to the sending state.
4. Conclusion

(1) WSN protocol needs to consider reducing energy consumption to extend network lifetime, while OPNET does not provide energy model to some extent, which affects its perfection.

(2) The process of WSN node working state transition is the premise of energy model modeling. According to this, WSN energy modeling is divided into three processes: node working state determination, node working state transition process real-time determination and using OPNET C language programming.

(3) The real-time determination mechanism of node working state transition process can be used to obtain the current value of battery load at the sampling time, and the core function of OPNET can be used to obtain the time stamp of sampling time. Then, according to the real-time estimation algorithm of battery life, the OPNET model of RM battery model can be realized, and then the energy process model can be constructed.

(4) The simulation results show that the determination mechanism of node working state and the real-time determination mechanism of node working state transition process are feasible; RM battery model can more accurately describe the battery discharge process than linear model, so as to more accurately estimate the battery life, that is, node life.

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