An OVSF Code Based Routing Protocol for Clustered Wireless Sensor Networks

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Abstract

LEACH series protocols are low energy consumption adaptive clustering routing protocols in wireless sensor networks which were firstly proposed by MIT scholars. Considering the disadvantages of the TDMA mechanism which has been used in LEACH series protocols, such as long time delay and high energy consumption, an improved routing protocol based on OVSF code in clustered sensor networks is proposed. Facilitated by its orthogonality and incoherence, the transmission can be realized based on the demands of the node, but not the time slot, during which the member node has to transmit data to the cluster heads. The simulation results show that the proposed OVSF code based routing protocol greatly reduces delay and energy consumption compared with TDMA based protocols.

Keywords: *LEACH; TDMA; OVSF; Delay; Energy consumption*

1. Introduction

Wireless Sensor Networks (WSNs) in which sensor nodes, sink and management node are deployed is a new kind of data-centric wireless network. As widely used in military, biological, transportation, environmental science, health monitoring and space exploration, etc., it has been recognized as one of the most important technology in the 21st century [8, 9, 10]. Routing protocols that can facilitate application specific services in WSNs constitute one of the key design objectives of current WSNs research. Although the routing protocol of wireless network is advanced enough, it cannot be directly applied in WSNs due to the characteristics of WSNs which is different from traditional wireless networks [11, 12]. An important challenge in the routing protocol design of WSNs is that two key resources—communication bandwidth and energy—are much more limited than in a tethered network environment. These constraints require innovative design to use the available bandwidth and energy efficiently. To address this issue, Heinzelman *et al*, firstly proposed a low-energy adaptive clustering hierarchy (LEACH) application-specific protocol [1, 2]. It improves system lifetime compared with general-purpose multi-hop approaches. Recently, a variety routing protocols have been proposed which were improvement version of LEACH protocol. Bara'a A. Attea *et al* proposed a new evolutionary based routing protocol for clustered heterogeneous WSNs [3]. Cheng Hong-bing *et al* proposed NHRPA, a novel hierarchical routing protocol algorithm for WSNs [5]. S. Hussain *et al* proposed using genetic algorithm for energy efficient clustered WSNs. Joe-Air Jiang *et al* presents a QoS-guaranteed coverage precedence routing algorithm [6] and V. Loscrì *et al* proposed TL-LEACH (Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy) in WSNs [7]. Almost all these improvement based on LEACH is to research a better clustering method to improve the performance of WSNs. However, the TDMA (Time Division Multiple Access) [13, 20] mechanism used or assumed in these protocols may cause long end-to-end delay and consequently high energy consumption because nodes have to send data to the sink at its own distribution time slot. To address this issue, we propose an improved routing protocol based on OVSF [14, 15, 19, 21] code transmission instead of TDMA. Compared with TDMA based protocol, the proposed OVSF based routing protocol greatly reduces time delay and improves the network energy utilization efficiency [11, 12, 13]. Moreover, it also facilitates sensor nodes localization. As we know, LEACH is based on 'round' and there are two stages in each 'round'. If we only consider the cluster head selection methods and ignore other aspects, it is not efficient on the performance improvement of WSNs. Thus we propose a new OVSF code based protocol to replace TDMA which greatly improves the utilization ratio of energy and the delay of WSNs. We don't focus on the clustering mechanism but the data transmission mechanism.

2. Related Work

Many researchers devote themselves to the optimal routing protocol in WSNs. The proposed routing protocol can be divided into two categories: one is the plain routing protocol, such as direct diffusion (DD) [23] and security protocol for sensor networks, and the other is the clustering routing protocol, such as low energy adaptive clustering hierarchy (LEACH) and power efficient gathering in sensor information systems (PEGASIS) [22]. Many researchers propose improved routing protocol based on the above protocols. LEACH becomes one of the most frequently improved routing protocols. The common point of the derivative protocols is that they do not change the transmission code mechanism. The transmission code mechanism is significant in a wireless network. In GSM network, we select the TDMA mechanism as the transmission mechanism. TDMA is the abbreviation of Time Division Multiple Access which divides time into cyclical frames and each frame is split into several time slots in which signal or data flow can be sent. This mechanism solves the problem of multi-users' communication at the same time. Meanwhile this mechanism is widely using in GSM which is Global System of Mobile communication and shows a great success in multi-users' communication. So researchers apply this mechanism into WSNs where the data transmission mechanism is not very mature. For LEACH, the TDMA mechanism distributes time slot to every cluster member, and the cluster member transmit their sensing data to the sink node following the time table. Through this mechanism the protocol realizes sensing data transmission among the cluster members and the cluster head. However, in many cases, sensors detect the environment parameter in real-time which leads to the requirement for real-time data transmission in WSNs. Considering the TDMA mechanism which divides time into several time slots, it doesn't meet the requirement of real-time scenarios because the smallest delay is equal or greater than the frame. Just as the improvement from 2G to 3G which adds the OVSF code as one of its data transmission mechanisms, in this paper, we propose an improved routing protocol based on OVSF code to meet the real-time requirement of WSNs in certain environment. Compared with 2G, in 3G the transmission rate is several times faster than before. At the same time in 3G mechanism all users' communication is at the same Frequency Band which increases the transmission rate. Another advantage of this mechanism is that time synchronization is not necessary which makes setting up a WSN more convenient especially when GPS system is needed.

3. The TDMA in LEACH

LEACH was proposed by MIT scholars Heinzelman *et al*. It is based on continuous cycle of cluster reconstruction which can be described using "round" concept. Each cycle is divided into two stages: cluster building stage and the stability of the data transmission stage.

During the stage of cluster building stage, cluster head selects a random number from 0 to 1, then the number is compared with T(n) of each node. If T(n) is greater than the random number, the node is selected as the cluster head (CH), otherwise the cluster member. The computation of T(n) is as follow:

$$T(n) = \begin{cases} \dfrac{P}{1 - p\left(r \bmod \frac{1}{p}\right)} & n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where P=k/n (k is the number of cluster and n is the total number of node) is the desired percentage of CH nodes in the sensor population, r is the current round number, and G is the set of nodes that have not been selected as CHs in the last 1/p rounds.

After the CH is selected, it broadcasts ADV news including the node ID and symbol, at the same time cluster member nodes receive different ADV news from different CHs for a period of time. According to the RSSI, the nodes choose to join a cluster with stronger signal, and nodes will reply Join-REQ news including the node ID, cluster head ID and identifier symbol. CH sends messages to all the cluster members, including the node ID, spectrum code and time table which is the TDMA table.

The cluster member nodes collect data, and in its own slot time it sends data to the CH. At the same time CH receives and gathers data, and transmits to the base station. In each round of second stage, each CH distinguishes the data from different nodes by TDMA which provides each node time slot, and each node must send data to its CH only.

TDMA which incises time into many cyclical frames and in which each frame is incised into several slot time again is generally used in wireless network protocol. It utilizes the frame mechanism to complete data transmission among different nodes. Since each node sends data at its specific time slot, it realizes the non-coherent information transmission between different nodes.

In LEACH protocol, at the stability stage of the data transmission, each CH transmits a time table to its cluster members. The time table sets the order of each node for transmission and each node transmits data only at its own specific time slot. The frame structure is as follows:

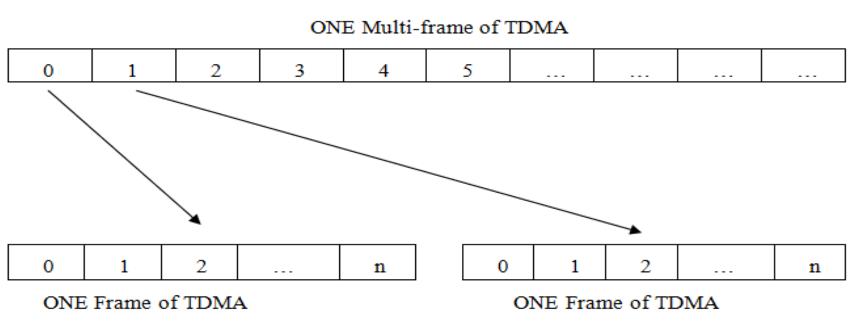

Figure 1. The Structure of Frame

The weaknesses of TDMA are listed as follows:

① Cluster members must send data to CH in every distribution time slot, so the rate of node energy utilization is low.

② For one specific node, the data transmission interval is a TDMA frame. The network delay of the total network can be greatly improved.

③ The TDMA mechanism needs time synchronization at beginning which causes unnecessary energy consumption. For WSNs, this leads to early death of nodes and cause the whole WSN permanently end.

Considering above weakness, in this paper, a new transmission mechanism based on OVSF code is proposed which effectively reduces the delay of the network and improves the utilization rate of the nodes energy.

4. Improved Mechanism Based on OVSF

4.1 The Principle and Mathematical Theory of OVSF

OVSF (orthogonal variable spreading factor) which is firstly proposed in 1997 by Adachi is a variable spread spectrum factors based on orthogonal code. Taking advantage of its orthogonal and inherence, it perfectly complete the data transmission in wireless communication. The mathematical theory of OVSF is as follows:

Set $\{C_N(n)\}$ where $n = 1,\ldots,N$ is a collection of orthogonal spread spectrum code which has length N. If the N orthogonal $C_N(n)$ is regarded as a row vector with length N, the row vector forms a N * N matrix C_N which can be recursively generated according to the following formula by $C_{N/2}$:

$$C_N = \begin{bmatrix} C_N(1) \\ C_N(2) \\ C_N(3) \\ C_N(4) \\ \vdots \\ C_N(N-1) \\ C_N(N) \end{bmatrix} = \begin{bmatrix} C_{N/2}(1)C_{N/2}(1) \\ C_{N/2}(1)C_{N/2}(1) \\ C_{N/2}(2)C_{N/2}(2) \\ C_{N/2}(2)C_{N/2}(2) \\ \vdots \\ C_{N/2}(N/2)C_{N/2}(N/2) \\ C_{N/2}(N/2)C_{N/2}(N/2) \end{bmatrix} \qquad (2)$$

The orthogonal code of variable length also can be formed with the structure of recursive tree. The spanning tree is as follows:

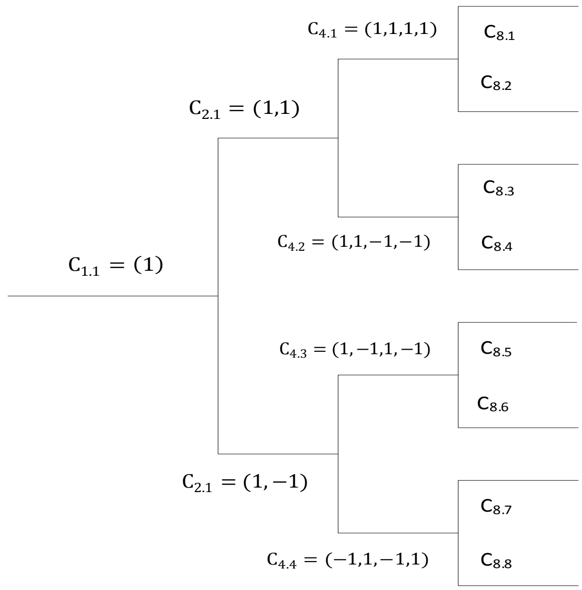

Figure 2. The Spanning Tree of OVSF

The proposed mechanism based on OVSF code realizes the optimal transmission by selecting better code when the number of cluster members is smaller than the vector length. At the beginning of the data transmission, the mechanism selects an optimal N as the layer of OVSF code spanning tree. The selection algorithm is shown in Figure 3.

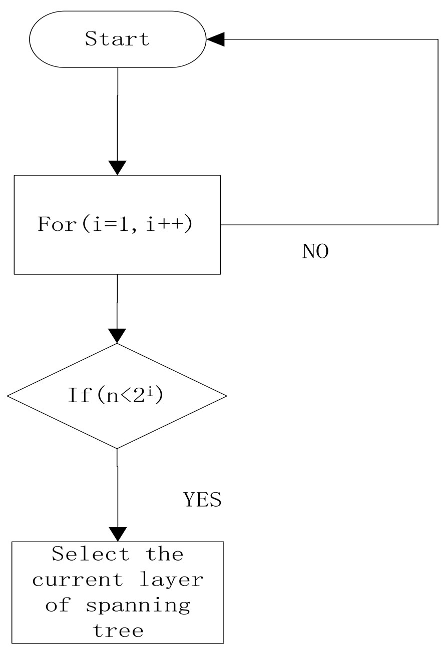

Figure 3. The Selection Algorithm of Spanning Tree Layer

After selecting a proper value of *i*, in the next step the distribution strategy of the OVSF code should be determined. In order to ensure the orthogonality of the physical channel, in the code tree, the code assignment principle is as follows: only if a code of backbone nodes and branch nodes are not assigned, the code can be assigned to a cluster member. For example, in Figure 4 which shows a 4-layer code tree, the assigned code is C_{11}, C_{22}, C_{16}. If we assign C_{16} to C_{12} and C_{32} to the new cluster member, we can make the code resource utilization rate 100%. It means that reasonable code resource distribution reduces the resistive rate and improve the code resource utilization rate.

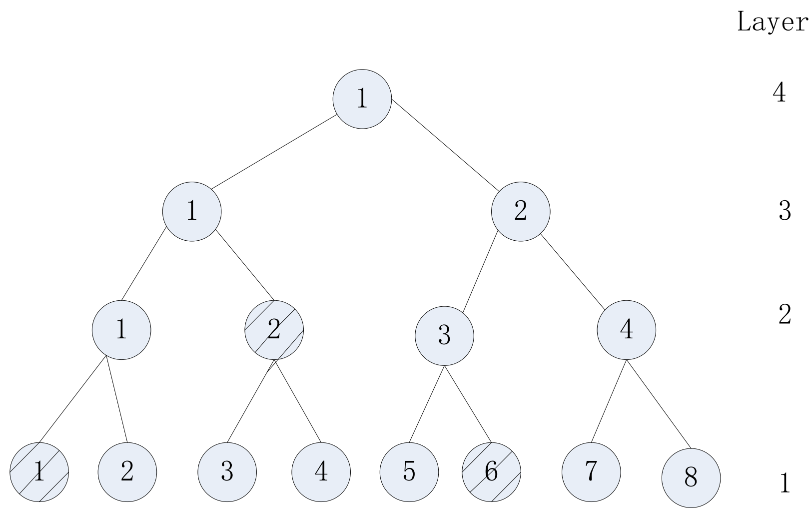

Figure 4. The Example of 4-layer Code Tree

While guaranteeing the code resource utilization rate, we should select optimal code to ensure the orthogonality of the nodes each other. As shown in Figure 4, we can see that if we select $C_{11,}$ the C_{21},C_{31} and C_{41} must not be selected as transmission code. If one code is released, in other words, one code does not act as a certain transmission code, in order to leave more space for the new node to select code, a dynamic algorithm is proposed for the re-assignment to keep the code resource utilization rate. The algorithm would be detailed stated in Sec 3.2.

4.2 The Process of Data Transmission Based on OVSF

The proposed OVSF based mechanism follows the process below:

1) the cluster head sends the OVSF matrix to its cluster members;

2) the nodes add a group of OVSF code in front of the data;

3) at the CH, we use the same OVSF matrix multiplied by the received data. Transmission process and decoding principle is shown in Figure 5.

For the OVSF code distribution mechanism, we select the DCA (Dynamic Code Allocation Scheme). As the name suggests, the allocated codes are dynamic in nature in the sense that a particular session may start transmitting with a particular OVSF code and end its session with a different code. The decision algorithm is shown in Figure 6. Through the DCA algorithm, while ensuring efficient use of the code resource the delay is reduced and the throughput of WSNs is improved. The proposed OVSF mechanism outperforms TDMA on the delay, energy consumption and throughput.

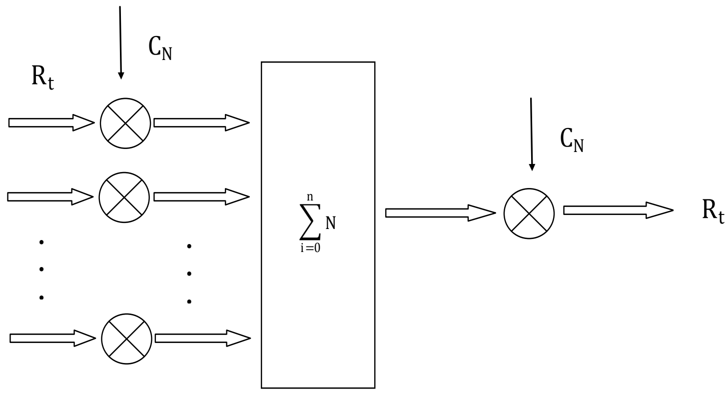

Figure 5. The Transmission and Decoding Process

As the Figure 2 shows, the data flow R(t) is transmitted by multiplying its distributed OVSF code and when the data flows arrive at the cluster head they are multiplied by the same OVSF matrix C_N. The CH identifies the data of its member through the OVSF code which is distributed at the stage of cluster building. As each OVSF code multiplies the matrix C_N whose rows are orthogonal each other, we can decode the signals using the following formula which shows the decoding principle:

$$\sum_{i=1}^{N_i} C_i(N_1, n_1) * Cj(N_2, n_2) = \begin{cases} 0 & n_2 \neq n_1 + jn_2 \\ N_1 & n_2 = n_1 + jn_2 \end{cases} \quad (3)$$

The data transmission process can be represented by equation 4.

$$R(t) * C_i * C_j = \begin{cases} 0 & i \neq j \\ iR(t) & i = j \end{cases} \quad (4)$$

where *i* is the serial number of the distribution of OVSF code and *j* is the row number of the matrix C_N which is multiplied by the data flows at the CH. The orthogonality and incoherence of each node has been utilized not only for indiscriminate data transmission, but also for reducing the delay and improving the energy consumption rate compared with the TDMA.

4.3 The Advantages of OVSF

The advantages of the improved routing protocol based on OVSF code transmission mechanism are as follows:

① Compared with the TDMA based mechanism, OVSF code avoids time synchronization process so that it effectively saves nodes energy.

② Under the OVSF mechanism, the cluster member nodes sends data according to their own needs so as to avoid the unnecessary energy consumption, and meanwhile, it reduces the network delay.

③ Because each node has its unique OVSF code, it is helpful to the nodes localization.

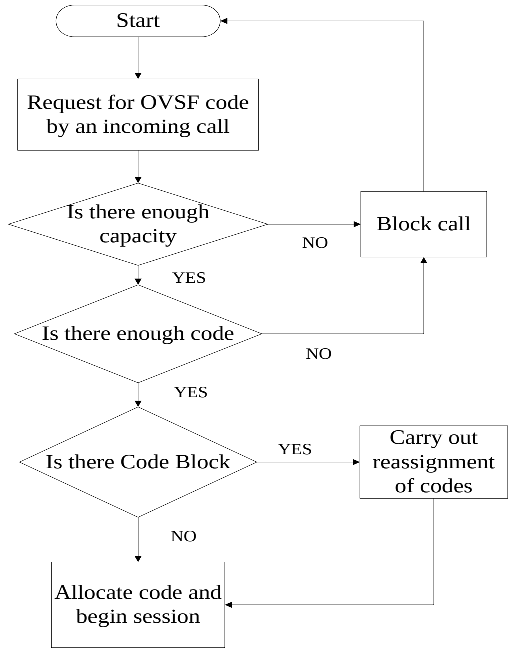

Figure 6. The Distribution Algorithm of DCA

5. Simulation Results

In this paper, we select NS-2.34 based on Ubuntu as the simulation platform to evaluate the new transmission mechanism that we have proposed. Details of the simulation environment are shown in Table 1. The distribution map of simulation nodes is shown in Figure 7.

As shown in Figure 7, the nodes are randomly deployed at a simulation scene of 100*100(m^2) in which the simulation parameters are set as in Table 1. With NS-2.34, we simulate the data transmission at the same simulation scenario under the LEACH and the Improved Routing Protocol based on OVSF code. Through the related Tcl programs we obtain the performance comparison data.

Table 1. Simulation Scenario Parameters

Network parameters	Value
Simulation area(m*m)	100*100
Number of node	101
The station of Sink	(200,200)
Initial energy (J)	1.5
Excvr(J/bit)	50E-9
Packet-size/bit	512
Simulation time(s)	600

In order to evaluate the performance of OVSF code transmission based mechanism, we compare the network delay and number of remaining nodes between TDMA and OVSF under the same simulation environment. The simulation is run ten times and we get the average value. We plot the graphs based on the average value which reduces the deviation to a certain extent. The results are shown in Figure 8 and 9.

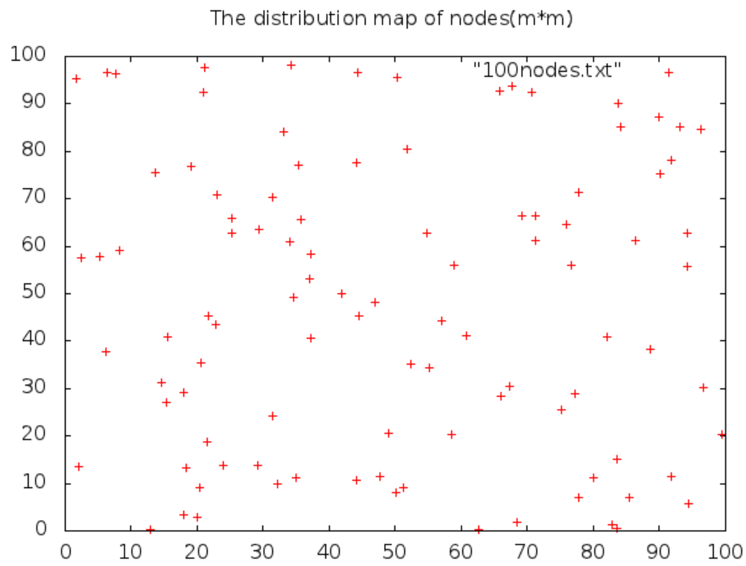

Figure 7. The Distribution Map of Nodes

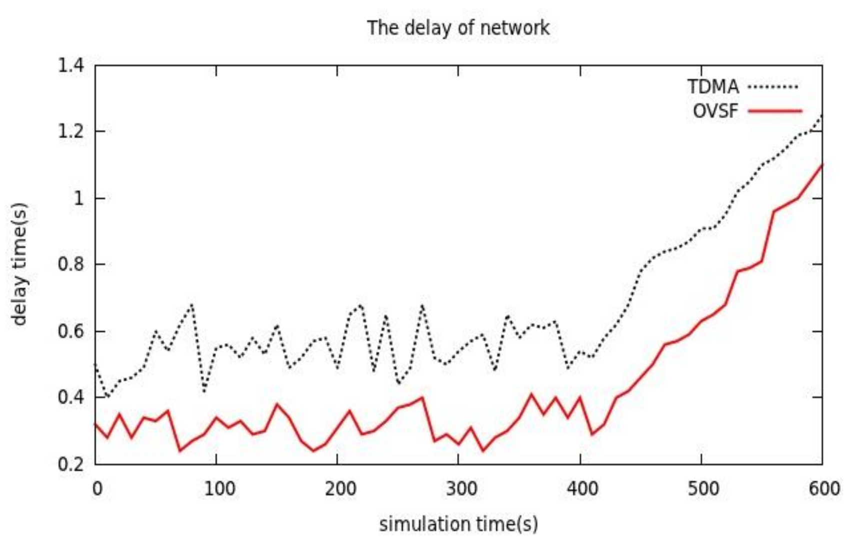

Figure 8. The Delay of Network

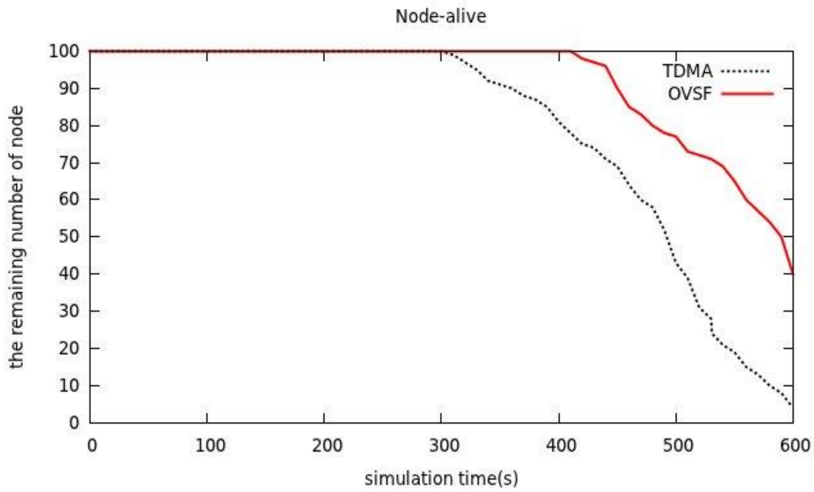

Figure 9.The remaining number of node

As shown in Figure 8 and Figure 9, the improved routing protocol based on OVSF code has lower delay of network and better the energy consumption rate. For the energy consumption ratio, we use the remaining number of the cluster members in one cluster as an evaluation standard. Obviously the improved routing protocol based on OVSF code outperforms TDMA based protocol on energy utilization rate.

6. Conclusions

Through the study of the original LEACH protocol and the improved series, in this paper, we proposed an improved routing protocol based on OVSF code transmission instead of TDMA mechanism to realize the incoherent data transmission. For OVSF code assignment, Dynamic Code Allocation Scheme is proposed to realize the efficient code resource utilization. Through the code tree the orthogonality of each other is ensured. Facilitated by the orthogonality the cluster members can realize the incoherent data transmission to the sink at the same time. Compared with LEACH whose data transmission mechanism is TDMA, the improved routing protocol based on OVSF code doesn’t need time synchronization and every cluster member transmits its detected sensing data to the sink or base station based on its needs but not the time table which makes the rule that the cluster member only transmit data at its own distribution time slot. The simulation results show that the improved protocol effectively reduces network delay and improves the node energy consumption efficiency, prolongs the network lifetime.

7. Future Work

Since we focus only on the data transmission mechanism at current stage, we may design efficient transmission code as well as optimal cluster head selection scheme in the future. Moreover, we may compare other performances of WSNs to prove our proposed transmission mechanism. We may also extend this mechanism to different scenarios such as mobile sensor networks.

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