Performance Evaluation of Virtual Routing Protocol EMRP in WSNs

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Abstract. Our developed protocol Energy Aware Mesh Routing Protocol EMRP is a robust, cluster-based routing technique used in Wireless Sensor Network (WSN) which provides a reliable, scalable, energy efficient multipath routing mechanism for data transmission to the Base Station (BS). EMRP is classified as a routing technique supporting network virtualization as it reduces energy consumption, improves energy balance and network lifetime of whole WSN by energy aware routing and evenly utilizing available energy each sensor node. In this paper, we clarify the data transmission process of EMRP, how it supports network virtualization and maintains its algorithms to monitor the residual energy of each sensor node to provide such advantages. We then analyze, evaluate and optimized EMRP design parameter that influencing network performance of WSN: total energy consumption, network balance and network lifetime.

Keywords: Cluster based routing, energy aware routing, virtual routing, virtualization, VSN, WSNs.

1 Introduction

Virtualization Sensor Network (VSN) collaborates a dynamic set of sensor nodes belonging to different WSNs that might be controlled or owned by different administrative bodies to perform a specific task [8]. By combining heterogeneous nodes of different WSNs for VSN it provides reliability, flexibility and scalability to WSN especially in the case that links within the network are broken. Figure 1 shows an example of VSN comprising of two sensor networks and other nodes

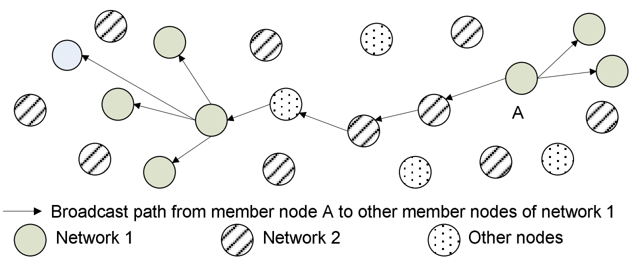

Fig. 1. VSN comprising two networks and other nodes

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In VSN, network and node resources play very significant roles for the operation of VSN. As power management is one of the most critical issues in WSNs, energy consumption for sending/receiving messages and the residual energy of the nodes and network is taken into account for VSN to work effectively despite the differences of heterogeneous nodes. Moreover, internetworking in VSNs make the energy consumptions of nodes between networks are greatly different therefore routing in VSN needs to work on important missions: energy saving, energy balance and scalability. Cluster-based protocols for heterogeneous networks provide better scalability and higher energy efficiency than other routing protocols. Energy aware routing helps to utilize node and network energy. Our cluster based energy-aware mesh routing EMRP use energy resources efficiently since it not only improves energy efficiency of VSN but also increases lifetime of nodes and of the overall network. The task of energy control and management in EMRP is simple, effective, scalable and involves less control overheads than other routing protocols thus work effectively in WSNs.

Recent research shows that hierarchical cluster-based routing has many advantages in increasing network performance in WSN[1]. Cluster based routing protocols such as LEACH[2], HEED[3] group nodes into clusters in which one or more nodes satisfying evaluation criteria such as highest remaining energy level are selected as Cluster Head (CH). CH aggregates data from its cluster members and sends aggregated data to a base station (BS) in a multi-hop mode. Since these protocols manage WSN nodes in clusters, they offer many advantages necessary for WSNs such as local management of clusters without obtaining information of the whole network, reducing overhead and data redundancy, reducing total consumed energy, distributing energy consumed evenly and finally increasing network lifetime. There are two approaches in hierarchical cluster-based routing protocols: time-driven and event-driven. In time-driven protocols, sensed data is periodically sent to the BS to provide information of the environment all the time whereas in event-driven protocol, sensed data is sent to the BS when an event is detected. Time-driven routing protocols usually form fixed clusters in the initializing stage based on probability formula while event-driven routing protocols only form clusters after detecting an event.

Event-driven hierarchical cluster-based routing protocols such as OEDSR[4], ARPEES[5] and HPEQ[6], EMRP[7] clustering and data transmission to the BS happens only when and where the event occurs (sensed value is greater than predefined threshold). Therefore event-driven approaches in WSNs are more efficient in saving energy, reducing redundant data and increasing network lifetime than time-driven approaches since they involve less overheads, data, energy usage and redundancies. Our recent analyses and simulation results showed that our protocol EMRP outperforms APREES, OESDR, and HPEQ not only in terms of providing reliability but also significant reduction on total energy consumption, improvement on both energy load balance and network lifetime [7]. EMRP provides reliability to the performance of the WSN as it uses alternative multipath for data transmission toward the BS. To make routing decision between these paths, an energy monitoring method is used by estimating and comparing relay node's and backup node's residual energy. A dynamic switch between relay path and backup path is not only done when one path is broken (due to link failure or nodes' out-of-battery) but also to maintain energy load balance among the network.

EMRP Routing Protocol consists of three stages: initializing, cluster forming and data transmission stages. In initializing stage, EMRP uses broadcast processes to find relay nodes toward BS for each node in the network. It selects one main node and backup node based on a link cost factor function where residual energy is the main parameter. At this stage, alternative optimal paths toward the BS are found and stored. In cluster forming stage, EMRP chooses a cluster head for a cluster formed by nodes which could sense an occurring event. The CH sets up a time slot called TDMA schedule for cluster members specifying when to send sensed data to CH and then gathers, aggregates data to a frame for sending to the BS. The final stage is the most important stage in the EMRP routing process. CH uses relay nodes found at the beginning stage to route data to the BS. Each node has two alternative relay paths and EMRP dynamically switch between these two paths based on switch level to route data to the BS. The energy aware switches between two paths help to improve the balance of network thus prolong network lifetime. What is the minimum threshold for the switch to maintain even energy load balance between nodes or how the frequency of the switch could affect network performance is an important issue that is resolved in this paper.

In this paper, we analyze the process of EMRP last stage - data transmission and the mechanism that energy aware multipaths work as a virtualized algorithm that monitor energy balance between nodes and make use of energy resources in the WSN regardless the operation of underlying layers. We then analyze, optimize EMRP design parameter EMRP switch level and evaluate its influence to network performance of WSN: total energy consumption, network balance and network lifetime.

The remainder of the paper is organized as follows: Section 2 discusses virtual routing in EMRP. Section 3 presents our analyses and simulation results of evaluation of EMRP switch levels**.** The last section is the conclusion of the paper.

2 Virtual Routing in EMRP

The more detailed analysis of EMRP is analyzed in three stages: initialing, clustering and data transmission.

Initializing Stage

In the set up phase of the network, each sensor node broadcasts REQ_RELAY packets containing node ID, residual energy and location to BS to its neighbors. Each node (except node which has direct communication with BS) then uses this information to choose a relay node and a backup node based on maximum values of link cost function F_{RN}.

$$F_{RN}(j) = E_{res}(j) \times \frac{1}{d(j,BS)} \times \cos\alpha_j \qquad (1)$$

where E_{res} *(j)* is residual energy - available energy of node j, *d(j,BS)* is the distance from the candidate node *j* to the BS, α_j is an angle value created by node *j*, CH and BS.

$$\cos\alpha_j = \frac{d(CH,j)^2 + d(CH,BS)^2 - d(j,BS)^2}{2d(j,BS)d(CH,BS)} \quad (2)$$

After the initializing stage, we have a meshed hierarchy network topology. Each node has two links one link to its relay node (RN node) and other to its backup node (BN node) as shown in figure 2. Each node stores node ID, residual energy and location of these two nodes.

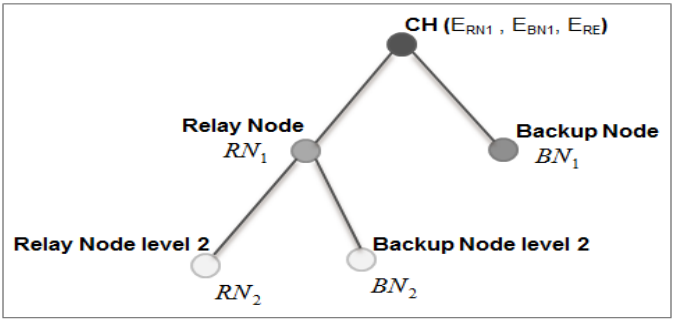

Fig. 2. Each node has two relay nodes RN_1 and BN_1

Cluster Forming Stage

When an event is detected in the network, nodes nearby the event become activated. Those nodes broadcast REQ_CLUSTER message (containing the node ID *i*, the amount of residual energy $E_{res}(i)$ and descriptive information of the sensed data *I(i)* from the event) to their neighbors. During a time t_1, each node receiving REQ_CLUSTER messages from all the other nodes and executes the link cost factor function (equation (1)). After t_1, the node which has the maximum value of the cost function sets itself as CH. The CH stores the node ID of all nodes, and then creates a TDMA schedule to assign each node a time slot. All non-CH nodes can use this time slot for transmitting their sensed data to the CH in order to avoid collision in data transmission. The CH receives data from all other nodes and prepare to gather, aggregate data to a frame and then selects relay nodes for creating a route to the BS.

Data Transmission Stage

The main idea of EMRP's transmitting process is energy monitoring method to make routing decision. In this method, each node estimates and compares its relay node's and backup node's residual energy. If either one of the node is out of battery or the difference between residual energy of relay node and backup node is below a predefined switch level, there will be a switch that relay node becomes backup node and backup node becomes relay node. The third stage of EMRP is described as following (illustrated with figure 2):

1th Step: After receiving data from all non-CH nodes, the CH will gather, aggregate and pack processed sensed data to a frame called DATA_TO_BS.

2nd Step: From the initializing stage, the CH saves the residual energy of RN_1 and BN_1 in its two parameters E_{RN1} and E_{BN1}. Then CH starts to send the first data frame DATA_TO_BS to its relay node RN_1.

3rdStep: When RN_1 receives DATA_TO_BS frame for the first time, RN_1 calculates total energy cost for both receiving one DATA_TO_BS frame from CH and relaying this frame to RN_2 using the radio model equation (3):

$$\begin{aligned} E_{total}(k,d) &= E_{Tx}(k,d) + E_{Rx}(k) \\ &= k\,E_{elec} + k\,E_{fs}\,d^2 + k\,E_{elec} \\ &= 2k\,E_{elec} + k\,E_{fs}\,d^2 \end{aligned} \tag{3}$$

Where E_{elec} is the power requirement on the electronics devices for transmitting and receiving the data, $E_{fs}$is the transmission amplification energy. Parameter k is message bit length, d is the transmission distance.

The RN_1 sends back to CH a RELAY_ENERGY message containing the energy cost $E_{Total}(k,d)$ and its current residual energy E_{RN1}. The CH saves this $E_{Total}(k,d)$ in its parameter E_{RE} and update E_{RN1} if needed.

4th Step: After having all three parameters energy residual of $RN_1 E_{RN1}$ and of BN_1 E_{BN1} and estimated spent energy for sending data to RN_1: E_{RE}, CH sends a DATA_TO_BS frame to RN, CH now estimates and updates parameter E_{RN1} corresponding to the residual energy of RN_1 each time a DATA_TO_BS frame is transmitted on the relay path using the below equation:

$$E_{RN1} = E_{RN1} - E_{RE} \tag{4}$$

Thus the CH from now on can continuously send the next DATA_TO_BS frames to $RN_1$for the next round while monitoring the current residual energy of RN_1 without further updating from RN_1

5th Step: At the same time of the 4th step, before transmitting a DATA_TO_BS frame, the CH needs to check two following conditions:

If bothE_{RN1} and E_{BN1} fall below a pre-defined *critical level* (for example 1% of node initial energy), it means that both relay and backup node do not have enough energy in order to continue to send data, the CH will broadcast REQ_RELAY messages again to find new relay and backup node.

If $(E_{BN1} - E_{RN1})$ is less than a pre-defined *switch level* (for example 0.5% node initial energy),RN1 will become a new backup node and the backup node will become the new relay node. For the first switch time, the new switched relay node repeats the 3rd step by sending back to CH total energy cost $E_{Tx}(k,d)$ in RELAY_ENERGY message so that CH can update the parameter E_{RE}.

6th Step: In the next hop, the relay node in turn serves as the CH using the same method to relay data to the next relay node, backup node and switch dynamically between them. This process is repeated until data frames reaching to the BS.

Since EMRP is mesh routing protocol it reduces a number of broadcast messages used find relay nodes in data transmission process and costs less control overheads of broadcasting. The task of energy management involves extra energy relay messages RELAY_ENERGY but these messages are only triggered to a specific target when necessary and do not consume a lot of energy (this is discussed in analysis and simulations in more details in section 3). The task of energy management is simple since relay node or backup node only needs to update its energy consumption of data frame to its upper node only one time when first time sending the frame (step 4th). By using residual energy of each node to monitor the switch between two alternative transmission paths and reducing control overhead of broadcasting processes, EMRP helps to utilize the energy resources and thus effectively supports VSN. Moreover, compared with other energy-aware routing protocols in WSNs, EMRP provides reliability, more energy efficiency [7]. The design of EMRP is energy monitoring method where each node is always aware of its relay node's and backup node's energy level. EMRP replaces nodes with new nodes if their energy falls below the critical level. Thus it eliminates the chance a node keeps sending data messages to its relay node when the relay node already runs out of energy, and hence improves the reliability and fault-tolerance of the event-driven cluster-based protocol. Moreover, the dynamic switch levels between relay node and backup node when the difference of their residual energy can reduce the energy consumption deviation of nodes along the transmission paths and achieve better load-balance compared to other event-driven cluster-based protocols. The energy monitoring method and dynamic switch levels better provides energy saving and energy balance therefore strongly supports virtualization sensor networks

3 Evaluation of EMRP Switch Level

EMRP is a mesh routing protocol which stores information of relay nodes at the set up phase of the network thus a number of broadcast messages used find relay nodes are reduced to in data transmission process. Besides, EMRP switch between relay nodes and backup nodes improves energy load balance and network lifetime. These two important issues of EMRP supporting VSN that are reducing control overhead, energy consumptions and providing energy balance due to EMRP switch levels are analyzed.

Since EMRP switch level helps to improve energy load balance between nodes of the network, thus energy consumption is spread evenly and network lifetime is prolonged, this section analyses how the variation of switch levels can influence the performance of EMRP. Switch level is threshold to switch roles between the relay node and the backup node in EMRP. When the energy difference between the residual energy of relay node and backup node is smaller than switch level multiplied by initial energy of a node, the relay node becomes backup node and vice versa.

$$\text{Switch level} = |E_{BN} - E_{RN}| \,/\, E_{initial} \quad (\%)$$

EMRP energy switches involve a number of relay energy messages. Although these relay messages consume a lot smaller energy than broadcast messages caused by the broadcast process, an appropriate level of switch is important to both reduce total energy consumption and maintain network balance. An appropriate switch level should be chosen to adapt to the length of event and frequency of switches. When the switch level is very low the switches happen so frequently resulting in extra overhead of energy relay messages RELAY_ENERGY. When the switch level is very high, fewer switches are done causing the disparity between relay and backup nodes and thus causing imbalance in node energy distribution. EMRP switch level therefore greatly affects the load balance of sensor networks and thus to network lifetime.

Simulations are setup to measure the weight of relay energy messages RELAY_ENERGY in energy consumption and to evaluate how the variation of switch level could make an impact on network performance and . For each simulated switch level, total remaining energy of network after each event, energy load balance of the network and network lifetime is estimated and evaluated.

Simulation Method and Metrics

EMRP algorithm with different switch levels were implemented in the OMNeT++ simulator [9], which is a public-source, component-based, modular and open-architecture simulation environment with strong GUI support and an embedded simulation kernel. Simulation parameters are the same for different switch levels. Table 1 describes the parameters used in our simulations.

The EMRP protocol is evaluated with different switch levels using the following metrics.

Table 1. Simulation Parameters

Parameter	**Value**
Initial Energy	1 Joule
Data packet size	500 bytes
Broadcast packet size	25 bytes
E_{elec}	50nJ/bit
E_{fs}	10pJ/bit/m2
Network area	800x800 m
Transmitting range	150 m
Sensing range	70 m
Number of nodes	200
Critical level	1%
Number of transmission rounds per event	5
Number of frames per round	6

In our simulations, we assume that all sensor nodes initially have 1-Joule energy. The simulation network contains 200 sensor nodes that are dispersed onto a field with square dimension. The transmission range is 150m and the sensing range is 70m. Data packet size is fixed at 500 bytes and broadcasting packet size is 25 byte. The low level is 10% of the initial energy. A node will stop participating in routing process if its energy falls below 1% of the initial energy. The simulation is run until all the sensor nodes that have distance to BS less than their transmission range die. That means all the links to BS are failed and data transmission process cannot continue. A round is defined as a complete transmission for one time CH sends all data that aggregates from its cluster. The number of data frames to be transferred in each round is 6 and the number of transmission rounds in each event is set to 5, therefore the number of frames per each event is 30. The switch level is ranging to evaluate its influence to network performance.

Result Analysis

We ran the simulation with 200 sensor nodes uniformly dispersed onto a 800x800 meters square field. The base station is located at co-ordinate (440,800) and 40-meter away from the closest sensor node.

Total Remaining Residual Energy

To compare network performance of each different EMRP switch level, we estimates the total remaining energy of network after each event for each simulated event. The simulation runs for 270 events.

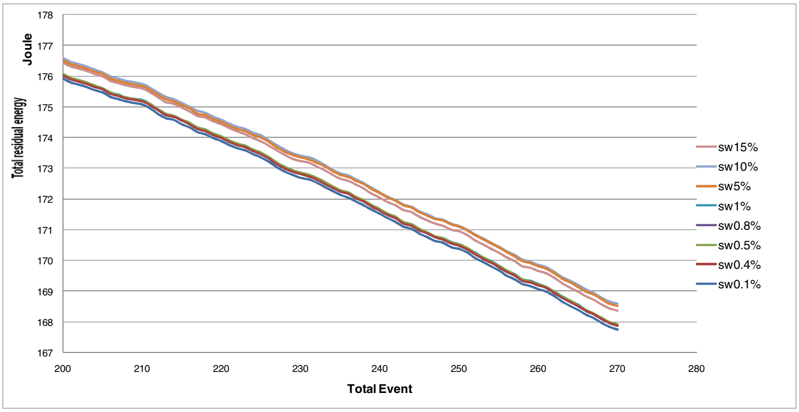

Fig. 3. Total remaining energy of network after each event for each EMRP switch level

The simulation results show that total remaining energy of the network after each event at different switch level cases is almost the same .Figure 3 shows that the total remaining energy of low switch level group is only approximately 0.3 Joule less than compared to that of high switch level group.

The difference of the energy consumptions after each event in different switch level cases is caused by RELAY_ENERGY messages to support the switch. However, the energy consumption of sending and receiving these RELAY_ENERGYmessages is relatively small compared to total network energy. This explains the difference of total remaining energy at different switch level cases is negligible. To clarify this analysis, we also compare the total consumed energy used to send and receive RELAY_ENERGY messages of different switch levels in EMRP after 270 events (shown in figure 4). The number of energy relay messages involved in switch level 15% is the least number among all cases958 messages and this number gradually increases to 5741 messages as switch level decreases to 0.1%. The total energy consumption caused by RELAY_ENERGY messages only varies from roughly 48mJ to 285mJ (a different of 237mJ).

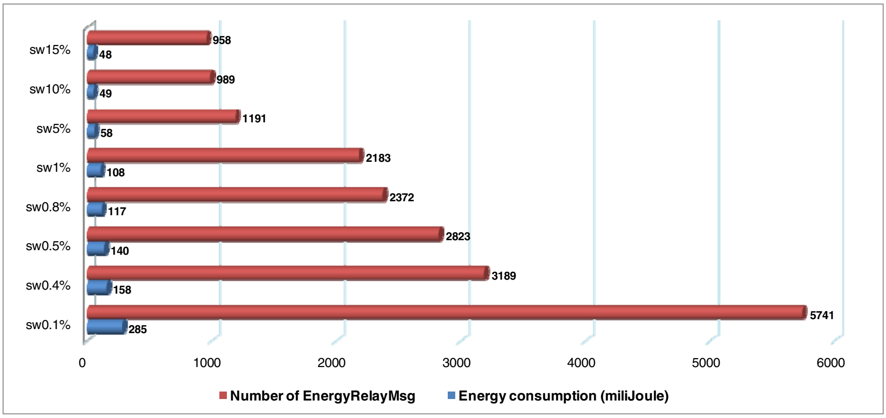

Fig. 4. No. of relay energy messages & their energy consumptions at different switch levels after 270 events

After 270 events, energy consumption to send and receive RELAY_ENERGY of different switch levels are under low as 285 mJ while total remaining energy of those is high as above 165000mJ (as shown in figure 4 and table 2).

Table 2. % of energy consumption of relay energy messages/total remaining energy after 270 events

Switch level	Percentage
0.1%	0.17%
0.4%	0.09%
0.5%	0.08%
0.8%	0.07%
1%	0.06%
5%	0.03%
10%	0.03%
15%	0.03%

Lower switch level involves in larger number of relay energy messages therefore higher energy consumption. Switch level 0.1% achieves highest percentage over total residual energy 0.17% while from switch level 5% and above achieves 0.03%. However, these consumptions are negligible to the total remaining energy of the network. From this simulation, it can be said that the adjustment of diverse switch levels does not make an impact on the total energy of network. The only consideration could be the number of overheads involved due to the number of relay messages although these messages cost low energy levels.

Load Balance

To evaluate the impact of switch level on energy load balance of the network, **three** groups of switch levels are taken to compare load balance of nodes after the network ran for 270 events. The graphs show individual remaining energy of 200 nodes corresponding to different switch levels in groups (0.1%, 0.2%, 0.3%, 0.4% và 0.5%), (0.6%, 0.7%, 0.8% và 0.9%) and (1%, 2%, 5%, 10%,15%) after 270 events

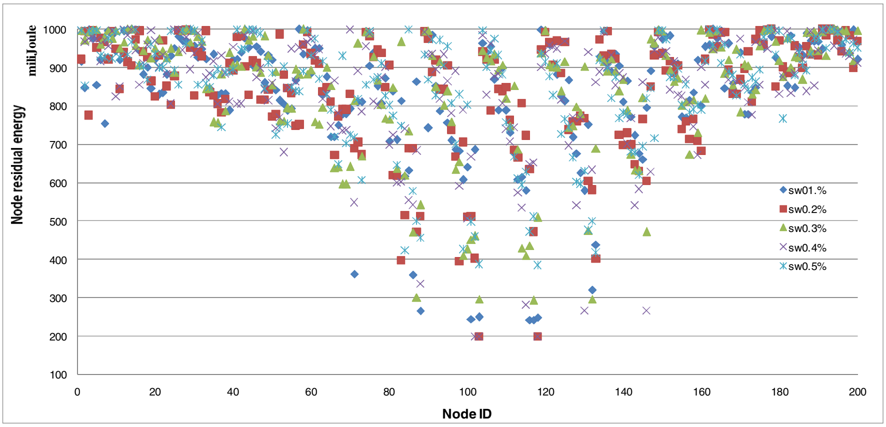

Fig. 5. Node residual energy distribution at switch level 0.1%, 0.2%, 0.3%, 0.4% và 0.5% after 270 events

Figure 5 shows that switch level 0.5% performs the best load balance performance. Nodes which have the lowest residual energy at level 0.5%are approximately 400 mJ at node energy falls under 300mJ, even around 200mJ at all other switch level. The worst switch level on load balance which energy of nodes falls low is 0.1%

Switch level 0.1% of initial energy should provide better load balance among others because the switch level is based on difference residual energy of back up node and relay node. The smaller this difference, the more frequent the switch between relay node and backup node, thus the better load balance of the network. The simulation results show the converse switch level 0.1% is the worst. This could be explained that at switch level 0.1%, the switch between relay node and backup node happens more often, thus resulting in an increase in energy to send and receive

RELAY_ENERGYcompared with other switch levels. Although the energy spent due to RELAY_ENERGY messages is small compared total remaining energy evaluated above, it does make an impact on individual node residual energy. Therefore it makes an impact on load balance thus switch level 0.1% is the worst energy balance case.

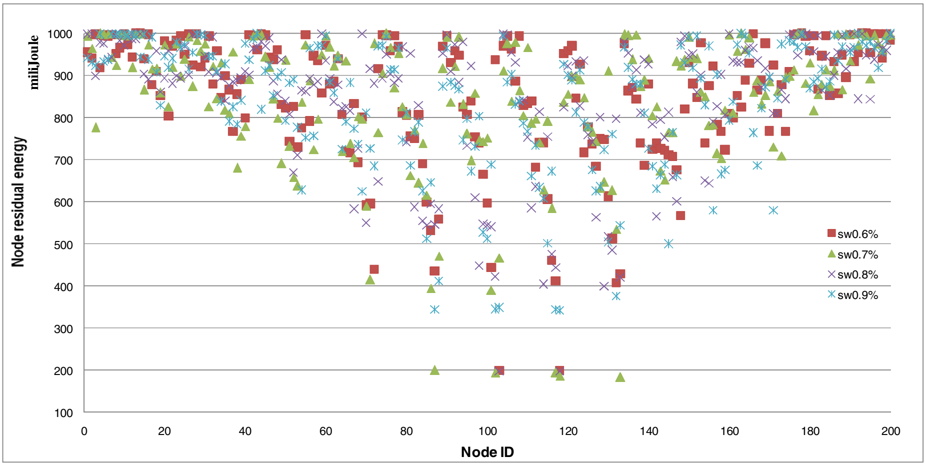

Fig. 6. Node energy distribution atswitch level 0.6%, 0.7%, 0.8%, 0.9% after 270 events

Similarly, as shown in figure 6 in this group of switch levels, the highest switch level 0.9% provides the best load balance among other switch levels 0.6%, 0.7%, 0.8%. The lowest energy level of nodes at switch level 0.9% falls roughly below 400ms.

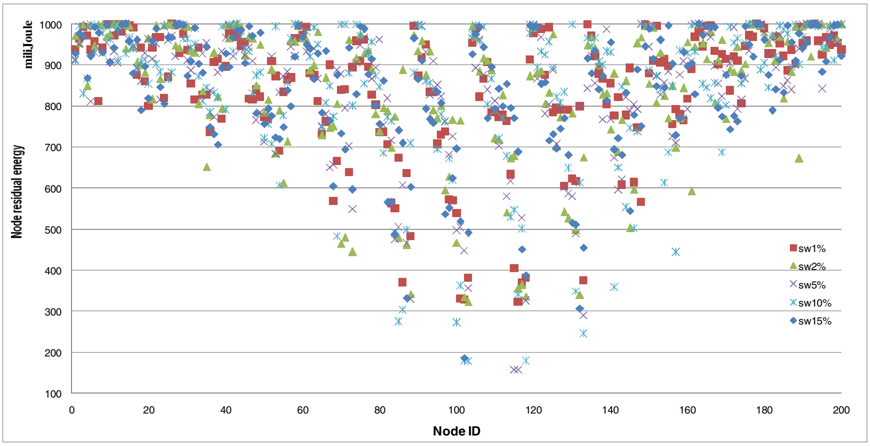

Fig. 7. Node energy distribution at switch level 1%, 2%, 5%, 10%, 15% after 270 events

As shown in figure 7, switch level 1%, 2% provides the better load balance among other switch levels. This could be explained by the higher switch level above 5% leads to lower number of switch between relay nodes and backup nodes thus resulting in smaller number of RELAY_ENERGY messages and smaller values of energy consumptions due to these messages. However, if the switch levels are too high, some nodes continuously became relay nodes thus energy spent mostly on these nodes thus resulting in imbalance of energy distribution. High switch levels therefore are not recommended as switches between relay nodes and back up nodes are done occasionally.

It could be concluded that EMRP switch levels greatly makes an impact on energy balance. Switch levels at the range of 0.4% - 2% initial energy give better load balance (summarized in figure 7) as it balances the number of energy switches and the energy consumptions due to the involvement of energy relay messages. From simulation results, switch level 0.5% gives the best load balance as it involves a reasonable number of switches and reasonable of energy relay messages. EMRP switch between relay nodes and backup nodes clearly improves energy load balance therefore EMRP switch plays an important role in supporting VSN.

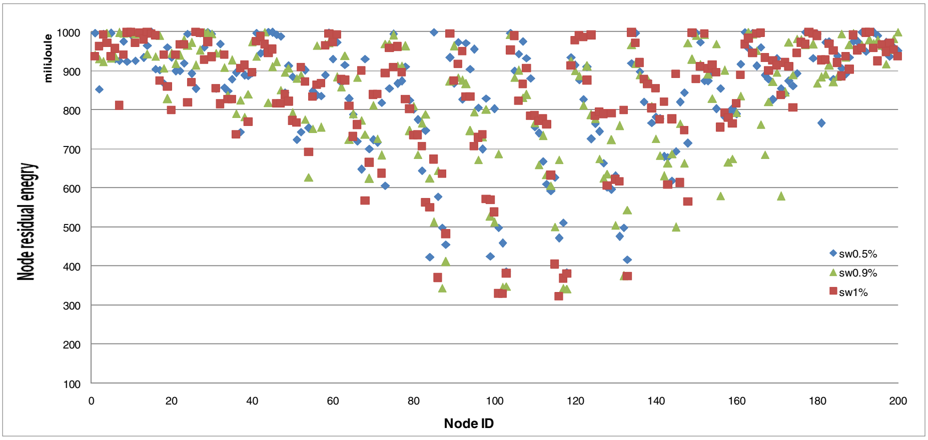

Fig. 8. Node energy distribution at 3 best switch level 0.5%, 0.9%, 1% after 270 events

Network Lifetime

Clearly, when many nodes are dead, then density of nodes decreases significantly, we will get low network connectivity. EMRP is designed to balance the node's energy consumption in order to avoid *hot spot*, which causes quick deaths of the nodes due to their overload. A well distributed energy load balance will make nodes last longer an increase network lifetime. The number of events at which the first node dies in the network and the total live rounds network can operate at different switch levels are

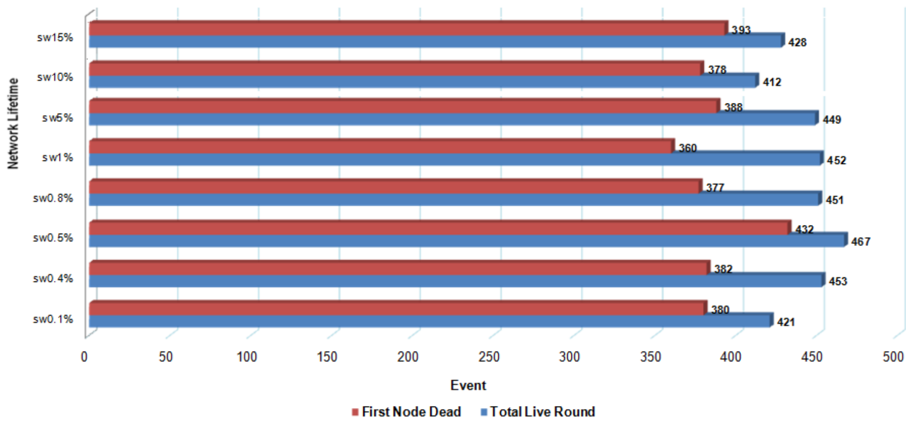

Fig. 9. Network lifetime and first dead node at different switch levels

measured. Switch levels 0.4 to 2% give better load balance therefore at these switch levels event that first node dies last longer and total live rounds (network lifetime) are more extended. EMRP switch between relay nodes and backup nodes clearly improves network lifetime therefore EMRP switch plays an important role in supporting VSN.

4 Conclusion

Virtual reliable EMRP routing concentrates on energy aware routing that reduces total remaining energy, improves energy balance and energy efficiency of VSN. Our analyses and simulation results show that energy monitoring method of EMRP based on switch levels is simple and effective since it involves less overheads of broadcasting processes and less energy consumptions and also greatly make an impact on load balance and network lifetime. By varying different switch levels, better energy balance and network lifetime is achieved. A range of switch level 0.4% - 2% works best for load balance and network lifetime since it balances between frequency of switches and number of involved relay messages, therefore this range better supports VSN.

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