LOCALIZED ENERGY EFFICIENT ROUTING FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

With the evolution of electronics, wireless sensor networks have been very popular in many domains of human life such as health, industry and military. This popularity has taken the attention on to the researches about wireless sensor networks. Wireless Sensor Networks are especially very favorable in conditions where it is physically difficult and dangerous for human being to gather information. Therefore, lifetime of those networks must be prolonged as much as possible, since it will be also infeasible to replace the energy depleted sensors with the new ones deployed in such geographical areas that are difficult and dangerous for human being to enter. In this paper, we present a localized energy aware routing method LEERA-MS and an alternative LEERA-MS-TH method that are used incorporation with an energy efficient sleep-wakeup schedule which is included with pipelining mechanism we have proposed before. Employing multiple sinks improve the performance by providing the fairly distribution of the load. Simulation results show that this routing method applied on a multiple sinks topology when employed together with the pipelined sleep-wakeup schedule provides 40% longer lifetime for wireless sensor networks.

Index Terms— Wireless sensor networks, energy efficiency, routing, power aware.

1. INTRODUCTION

Developments in electronics and hardware technology have yielded new devices called sensors. Those tiny devices mainly consist of a sensing mechanism, a processor, and a communication mechanism. Physical data is gathered by the sensing mechanism and transmitted to the data collection center called sink. Those sensors and their communication protocols form the Wireless Sensor Networks (WSNs). Wireless sensor networks generate a class of ad hoc networks. However they differ from traditional ad hoc networks in many ways. First of all, the nodes in WSNs are deployed in a more intensive manner than the nodes in traditional ad hoc networks. Besides, nodes in most of the traditional ad hoc networks communicate in point-to-point manner [1]. However, since sensors nodes are small energy constraint devices, their power sources and radio transmission ranges are limited. Radio performances of sensor nodes at both indoor and outdoor environments are investigated by Matthew et al [2]. According to their experiments, if both communicating nodes are resided on the same plane, coverage area is approximately 13.5 meters. If one of them is located at a higher position of the other, then the coverage area widens to 30 meters. Otherwise, if they are both risen up from the floor to a higher position, then the coverage distance rises to 45 meters. Therefore, data collected by sensor nodes can not be directly transmitted to the sink. It has to be relayed by multiple other inter relaying nodes in order to reach the sink. Thus, they use multi hop communication which is solely based on broadcasting mechanism. Furthermore, some WSN applications entails higher mobility. When the differences mentioned above are taken into account, it can be easily noticed that every method and protocol used for traditional ad hoc networks cannot be applied to all wireless sensor network applications [1].

In this work, the energy gain provided by the pipelined sleep-wakeup schedule we have proposed before, is developed further by combining it with a localized power-efficient, load balancing routing method. In most of the methods considering the neighbor nodes' residual energy levels locally, knowledge of the remaining energy levels of the neighbors in the coverage must be obtained to the sender node. This knowledge is provided by periodically broadcasting the energy levels between the nodes or making estimation in a way. Transmitting the energy levels periodically or on-demand brings too much overhead to the network and causes redundant energy consumption. However, with the method we propose here, there is no redundant overhead of transmitting energy level updates. Besides, in order to ensure a fair load distribution on nodes, it is provided for the consequent transmissions to follow a distinct path as much as possible. This method prolongs network lifetime almost 40% by including the wakeup schedule we proposed before [3-4].

2. RELATED WORK

Most of the conventional routing methods applied in traditional wired or wireless networks are inconvenient for wireless sensor networks. Since wired networks and other ad hoc wireless networks are not energy constrained as

WSNs, most of the routing algorithms work in those networks aim to find the best path such as the shortest one or one with the maximum bandwidth for transmission. Obviously, delay is very critical for some applications such as in military or health. However, not all of the applications are so sensitive to delays. For such applications, routing algorithms should be developed so as to construct paths that will contribute to the prolongation of the network lifetime.

Greedy Perimeter Stateless Routing (GPSR) [5] exploits geographical position information of nodes for the next hop decision. Before sending a packet, the transmitting node calculates the distance between all its neighbors and the sink. It forwards packet to the closest neighbor to the sink.

Another energy aware routing algorithm is the localized energy aware restricted neighborhood for ad hoc networks (LEARN) [6]. In this method, sender node chooses a neighbor having the largest distance from it in a particular area. This idea may not work all the time. Traditional greedy forwarding [4] is applied to some situations in which this theory does not work.

In SPIN [7], a node broadcasts an advertisement packet before sending a data. This advertisement provides description about the following data transmission. Nodes dealing with the data packet reply with a request. Following all these pre-sending notification traffic, sender node broadcasts the data packet to the demanding nodes.

Low-Energy Adaptive Clustering Hierarchy (LEACH) [8] is an energy-efficient cluster-based protocol. Nodes stay in sleep state beyond the transmission times dedicated to them by the cluster head. If they have packets to be transmitted, they have to relay packets to their corresponding cluster head in this dedicated period. After cluster heads get all the packets from the nodes in their clusters, they aggregate and compress it. Finally, the cluster heads relay this aggregated or compressed data to the sink.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [9] is constructed over a chain structure. PEGASIS is mainly based on the idea proposed by LEACH [8]. However, PEGASIS does not provide adequate energy efficiency for sensor networks because of the reason that transmission of global network information between nodes brings too much overhead which causes redundant energy consumption.

3. LOCALIZED POWER AWARE ROUTING WITH AN ENERGY EFFICIENT PIPELINED WAKEUP SCHEDULE (LEERA-MS)

3.1. Sleep-Wakeup Schedule

For event-based applications, sensor nodes are usually in the idle state to monitor the environment as mentioned in STEM [10]. We consider this approach in our scenarios too. If a sensor node detects an event, it gets out of the idle state and starts to transmit current data towards the sink. All sensor nodes are equipped with two radios and use two radio channels devoted for data communication and signaling as shown in Figure 1.

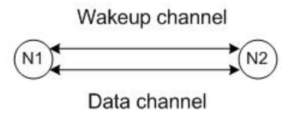

Fig. 1. Signalling and data channels.

Figure 2 depicts a simple communication scenario of three nodes. $Node_a$ has data destined to $Node_b$, however $Node_a$ has to wait for the wakeup period of the signaling channel. When the wakeup time comes, $Node_a$ starts to send beacons to $Node_b$. At this time, the signaling radio of $Node_b$ is already turned on and listens to the signaling channel if there is a beacon addressed for it. By the time it realizes the beacon, it replies with an acknowledgement and activates its data radio. $Node_a$ starts transmitting its data. Since the data radio of the next hop denoted by $Node_c$ is turned off, $Node_b$ cannot immediately transmit the data retrieved from $Node_a$. Thus, it has to wait until the next wake up time to start the process again.

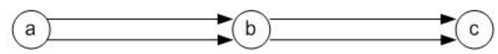

Fig. 2. Simple scenario.

State transitions of all three nodes are shown in Figure 3.

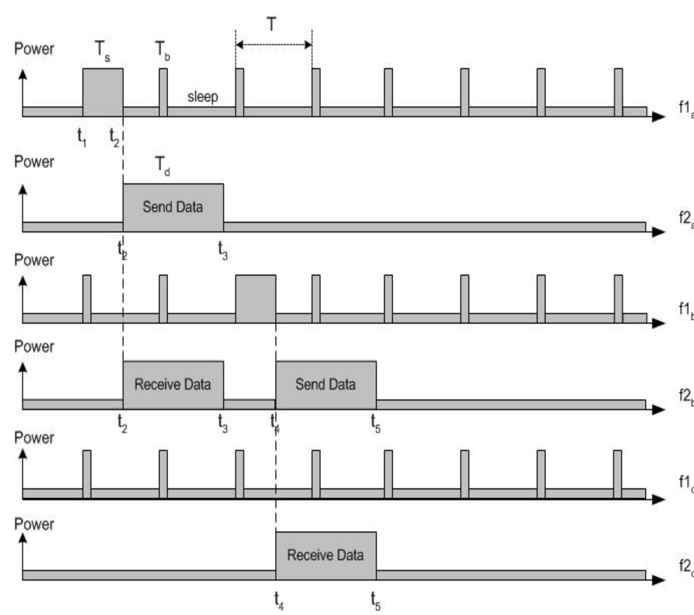

Fig. 3. Send-receive operations for STEM.

Pipelining method in STEM gives the nodes an opportunity of interacting with each other simultaneously. In this way, $Node_b$ sends an acknowledgement to $Node_a$, from which it received RTS packet. $Node_b$ also defines next hop address as $Node_c$ inside this broadcasted acknowledgement. By the time $Node_c$ realizes its address as the next hop, it immediately activates its data radio and becomes ready to receive. Thus, $Node_b$ will not have to wait for $Node_c$ to wake up as it is shown in Figure 4. All delays such as propagation and processing delays are ignored.

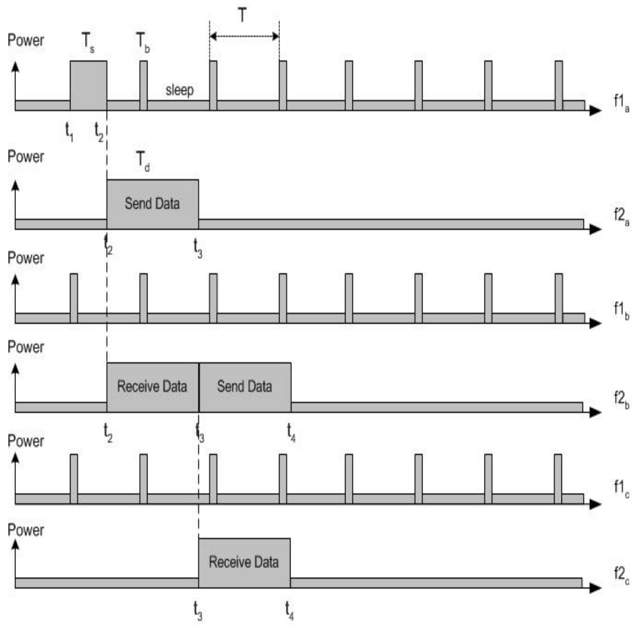

Fig. 4. Send-receive operations for STEM with pipelining.

As it is proposed in [4], by including pipelining into STEM, significant amount of improvement in latency is achieved as it is clear in Figure 5.

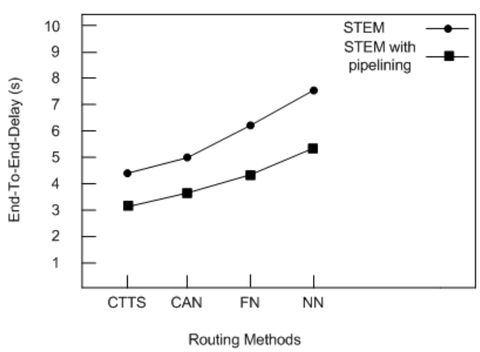

Fig. 5. End-to-End-Delay with STEM and Pipelined STEM

In Figure 5, routing methods denoted by CTTS, CAN, FN and NN represents Closest-to-the-sink, Closest-angled-node, Furthest-node, Nearest-node schemes respectively.

3.2. LEERA-MS

Main challenge considered with WSNs is designing and developing energy efficient communication mechanisms. Designing energy efficient routing methods is one of the approaches employed for the aim of prolonging the lifetime of the networks. Traditional routing methods used in wired networks like shortest path algorithm, can not be employed in WSNs because of the reason that by using the shortest path algorithm, all of the packets emerging from a source node will follow the same path on the way to the sink.

Several methods have been proposed for energy efficient routing in wireless sensor networks. Two main approaches have been applied. First one is the global knowledge about the energy levels of the nodes in the topology. In order to provide that global knowledge to every node in the network, a large amount of messages should be carried inside the network. These informing messages can be sent periodically or can be sent when an energy level change occurs. Link state or distance vector type algorithms can be applied in this state. However, while transmitting this information between the nodes all over the network, there will be incredible energy consumption which is the main challenge and problem considered and tried to be solved in wireless sensor networks. The second approach is making the routing decisions according to the local information about the nodes in their communication ranges. Giving routing decisions according to the local knowledge can be assured in two ways. One of them is the way in which the nodes probing their residual energy levels periodically which is also an energy consuming procedure. Other alternative method is the one which we propose here, recalculating the residual energy level of the sender and the receiver nodes by the information overheard in the RTS and CTS messages. By employing RTS/CTS mechanism, every node in the communication range of communicating pair of nodes is informed about the details of forthcoming transmission. Since the amount of data is identified in the RTS and CTS messages, all neighbors of both the sender and the receiver can calculate how much energy will be consumed by both the sender and the receiver according to the formulas given below:

$$E_{Transmit} = T_d * P_{Transmit} \tag{1}$$

$$E_{Receive} = T_d * P_{Receive} \tag{2}$$

With respect to the origination of consequent packets from a single node, there will arise congestions at the nodes residing in the middle of the topology. In parallel with the increasing packet intensity, packets will suffer to delays. Those delays are not the same as the back-off times in CSMA-CA. Since a periodic sleep-wake up schedule is employed in this project, although the back-off timer of a node expires, that node can not capture the physical channel immediately. It should wait for the next wake up period in order to send its data.

An alternative solution we propose in this paper for that challenge is spreading the consequent emerging packets all over the topology as much as possible, which also helps distributing the load over more nodes. However, sufficient amount of spreading is constricted unless multiple sinks used. If there is employed only one sink in the network, all subsequent packets try to follow a path around a certain line-of-sight. Therefore, always the nodes positioned around that certain line are employed in forwarding process. Besides, when a packet gets closer to the sink, it will compulsorily need to arrive to the node positioned around the sink. Hence, nodes residing around the sink deplete of energy quickly. This situation is called the hot-spot problem which is discussed in [11]. Data collected by sensor nodes can not be directly transmitted to the sink. It has to be relayed by multiple other inter relaying nodes in order to reach to the sink. Obviously, always the nodes resided around the sink will have to take charge during relaying of the packets to the sink. Hence, those nodes located in the hot-spot area will quickly deplete of energy and die. Death of those nodes does not only affect themselves or data communication of the area they are located. Since they are the only ones needed to convey the packets arrive from other parts of the network to the sink, all of the communication can crouch. This situation is depicted in Figure 6 clearly.

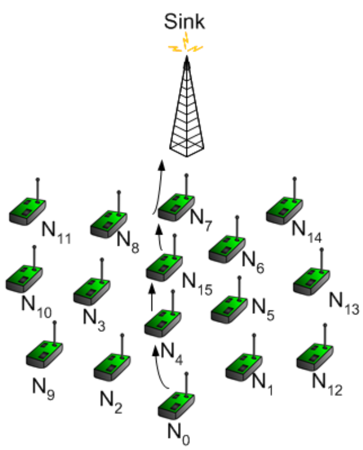

Fig. 6. Sample scenario with LEERA.

N_7 is the only last hop that can relay packets to the sink. Therefore, N_7 is the first node that will deplete of energy. However, if multiple sinks is positioned in the topology, packets emerged from N_0 do not have to travel around a single line towards N_7. As it is represented in Figure 7, when multiple sinks are used, nodes trying to forward the packet can direct the packet to the most suitable sink in the topology. By this way, N_7 does not have to perform as last hop compulsorily. Nodes N_{11}, N_8 and N_{14} can be employed as a last hop through a sink.

With LEERA-MS, topology is divided into grids vertically. Every sink owns a grid area and every node residing in this grid area takes up this grid's owner sink as the reference sink, and makes geographical positional calculations according to that sink's coordinates. In LEERA-MS, during choosing the next hop, firstly the energy levels are considered. If all neighbors have the same amount of energy, this time the one that makes the largest angle towards the corresponding sink is preferred. By choosing a further node, nodes located around the line-of-sight from the originating node towards its corresponding sink, will be saved of a possible congestion.

During the transmission of the first packet, since all neighbors of N_0 have same amount of residual energy, first packet emerging from N_0 will follow the shortest path denoted by $N_4 \rightarrow N_{15} \rightarrow N_7$. For the second packet, the same path is not used again. Since N_4 is employed in the forwarding process of the first packet, other neighbors of N_0 should be used this time. The one which has a larger angle towards the originator's reference sink is chosen as the next hop. Let's assume that N_1 has a greater angle towards the sink of the originator of the packet and chosen as the next hop. Following next hop for the second packet is chosen through the nodes N_4, N_5 and N_{13}. Since N_4 is employed in forwarding process of the first packet, it should be exempted this time. Again, there are two alternatives N_5 and N_{12}. N_{12} has a larger angle towards the reference sink of N_0 than N_5 and is chosen as the next hop. Following next hop is selected through the nodes N_{13} and N_5. Depending on the residual energy levels and the angle towards the corresponding sink, N_{13} is selected. Last hop before the second packet arrives at a sink is chosen through the nodes N_{14} and N_6. Since there are multiple sinks and N_{14} can directly relay the packet to its corresponding sink, it is chosen as the next and last. In the same manner, third packet will follow the path $N_2 \rightarrow N_9 \rightarrow N_{10} \rightarrow N_{11}$ as it is depicted in Figure 7.

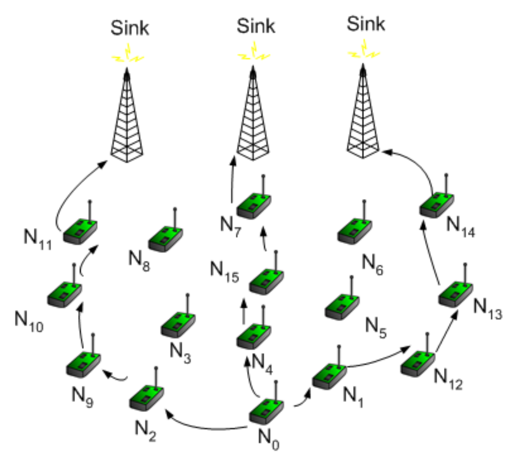

Figure 7. Sample scenario with LEERA-MS.

3.3. Load Balance Routing with an Energy Threshold Level (LEERA-TH)

Another alternative routing method we propose is combining the method LEERA with a threshold mechanism in order to decrease the end-to-end delay. In this mechanism, a threshold remaining energy level is predefined and nodes can apply Shortest Path method for choosing the next hop until the closest neighbor to the sink consumes its energy until predefined threshold level. If the sender node realizes that the closest neighbor has only as much as threshold amount of remaining energy, it applies the energy-aware routing algorithm henceforth and chooses the next hop according to the LEERA-MS.

4. PERFORMANCE EVALUATION

Simulations are performed on a simulator written in C++. A similar to 802.11 CSMA/CA MAC is employed in order to avoid collisions. We use the following terms in our simulation:

T_d : Time period for data transmission (All data packets are assumed to be same length).

T_s : Setup latency; the difference between the time that a sender starts to send beacons for a specific receiver and the time it gets an acknowledgement from the receiver.

T_b : Time for every node stay awake on f1 in order to determine whether any call for it is presented.

T : Time period for a node to wake up.

B_1 : Transmit time of a beacon.

B_2 : Inter-beacon spacing.

We calculate average Ts as in STEM:

$$T_s = (T + B_1 + B_2) / 2 \tag{5}$$

Values assigned to the variables are:

$B_1 + B_2 = 150$ ms, $T_d = 4000$ ms, $T_b = 225$ ms, $T = 600$ ms

We get characteristics of power consumption of the radio simulated from [12]:

$P_{Transmit} = 14.88$ mW, $P_{Receive} = 12.50$ mW ,

$P_{Idle} = 12.36$ mW, $P_{Sleep} = 0.016$ mW .

We ignore processing and other delays and accomplish the program by employing the topology depicted in Figure 8. There are 176 nodes and 10 sinks in the topology. Network area is parceled into grids and every node belongs to a grid and thereby referenced to a sink depending on its geographical position.

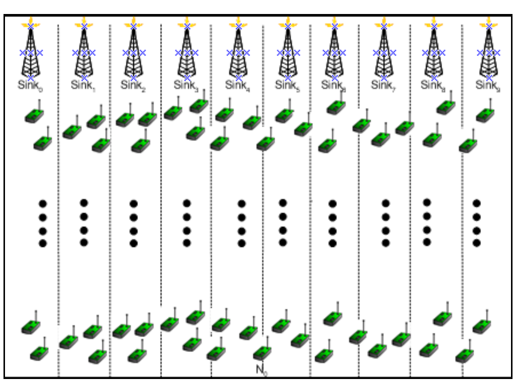

Fig. 8. Simulation topology.

Simulations are performed on a single scenario in which 50 packets that each takes 0.2 ms to transmit point to point, emerge from N_0 with 0.1 ms intervals consequently:

Three different routing methods are simulated and compared with each other. First one is the Shortest Path algorithm which employs the idea of choosing the neighbor closest to the sink. Second routing method is the Localized Energy Efficient (LEERA-MS) routing approach that makes forwarding according to the residual energy levels of the nodes in combination with their angles towards the packet originators' sink. And the last method simulated is the one (LEERA-TH) in which threshold mechanism is included into LEERA-MS. Total energy consumption in the network when applying three different routing methods mentioned above, is represented in Figure 9.

The amount of energy consumed by a single node and by whole network for a duration of *LifeTime* is calculated as follows:

$$E_{spent} = E_{wakeup} + E_{transmit} + E_{receive} \tag{6}$$

$$\begin{aligned} node[i].energyspent &= ((LifeTime/T) * T_b * P_{Idle}) + (T_d * P_{Transmit} * node[i].sndcounter) \\ &+ (T_d * P_{Receive} * node[i].rcvcounter) + (T_s * P_{Transmit} * node[i].sndcounter) \\ &+ ((B_1 + B_2) * P_{Receive} * node[i].rcvcounter) + ((LifeTime / T) * (T - T_b) * P_{Sleep}). \end{aligned} \tag{7}$$

$$E_{total} = \sum_{i=1}^{n} Espent_i \tag{8}$$

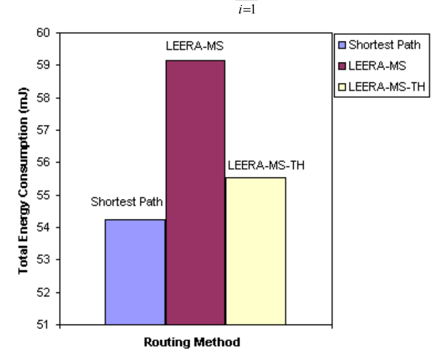

Fig. 9. Comparison of total energy consumption in the network for each routing method.

As it is clear in Figure 9, total energy consumed by all nodes in the network is higher when the energy aware routing algorithm is used as the routing method. At first glance, the result can be seen strange to the reader, however, the idea in our approach is to prolong the lifetime of every node thereby to prolong the lifetime of the network. The reason of our algorithm causing more energy to be consumed totally is that, packets travel a longer way because of choosing the nodes with more residual energy levels on the way to the sink. Shortest path algorithm seems to consume less energy than LEERA-MS. However, since the Shortest Path method uses always the same path for the same source-destination pair, the nodes on the path will quickly deplete of energy. One way of healing the total energy consumption because of stretching out the way to the sink, is employing LEERA-TH method. LEERA-TH does not cause to consume as much energy as LEERA-MS because of the reason that up to a predefined critical threshold energy level, shortest path algorithm is applied. When the amount of consumed energy by the nodes in the neighborhood of a sending node reaches to the critical threshold value, then energy aware routing is put into use. Thereby, a better end-to-end transmission delay is achieved. But of course, there is always a trade-off between energy and delay.

Figure 10 shows the transmission time for transmitting all packets emerged from N_0 to the sink. Since residual energy levels of the nodes are concerned during transmission between two nodes, rather than closeness to the sink or to the sending node, packets travel along more nodes and a longer path. This situation takes a longer time for the last packet to arrive to the sink as shown in Figure 12. Since energy levels of the nodes are not concerned with Shortest Path algorithm, it takes minimum time for a packet to reach to the sink.

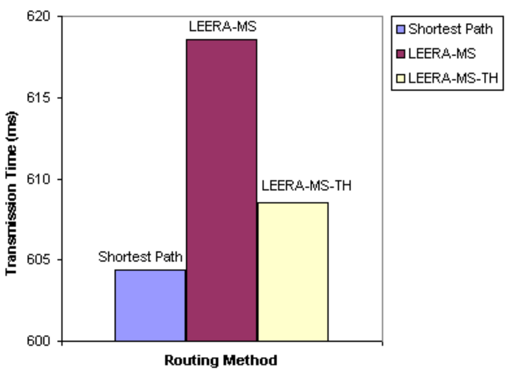

Fig. 10. Transmission time.

Figure 11 represents the energy consumed by the node with the smallest residual energy level after all transmissions.

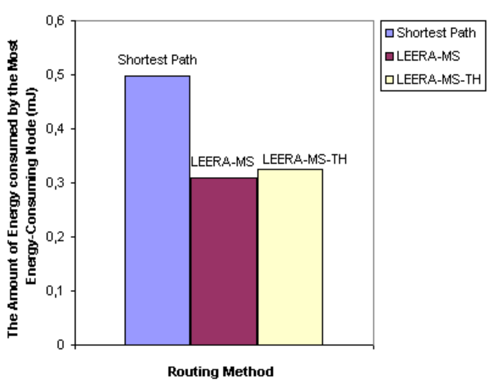

Figure 11. **C**omparison of energy consumption of the node with the smallest residual energy level.

Obviously, energy consumed by the least residual energy level node is smaller for LEERA-MS and LEERA-TH than Shortest Path routing method. LEERA-MS outperforms other methods with a performance about 40% better than Shortest Path and 5% than LEERA-TH in terms of network lifetime which is obviously depicted in Figure 12.

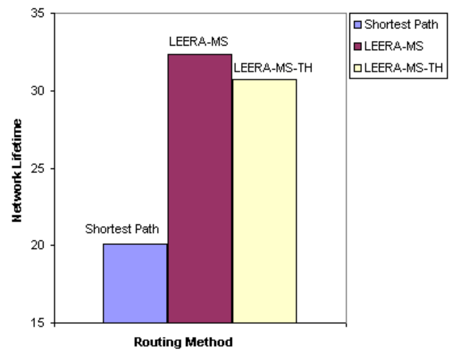

Figure 12. Comparison of network lifetimes

5. CONCLUSION

In this paper, we proposed a localized power aware routing method constructed over an energy efficient sleep-wake up schedule. Energy levels of the nodes in a network must be noticed to every node in the network. Accordingly, in recent studies energy levels of nodes are broadcasted either in a neighborhood locally and periodically or in a flooding way from sink to every node in the network. Furthermore, some studies make energy cost estimates for the nodes in the network which is unreliable. Obviously, transmission of energy level informing data in the network brings too much overhead to the network. Besides, nodes trying to convey this information consume energy which is the main challenge in WSNs to be considered while designing a method. In our approach, nodes already transmit RTS-CTS pairs to inform each other about a forthcoming transmission. Nodes do not perform an extra transmission to inform their neighbors about their residual energy levels. In addition, they do not have to make any cost estimation which might not provide accurate data. In the method proposed here, end-to-end delay increases because the same path is not always used for consecutive transmissions between the same source-destination pair. Path followed by the packets changes according to the residual energy levels of nodes in the network locally. Accordingly, the number of nodes that take action in the forwarding process increases. Furthermore, as the number of forwarding nodes increases, total energy consumption of the network also increases. On the other hand, the main aim of WSN topology and protocol design is to prolong the lifetime of the networks. Prolonging the lifetime of the network can only be assured by distributing the load balance all over the network which means using as different paths as possible during a traffic flow. Numerical results of our method show that nodes live 40% longer than the situation when Shortest Path routing algorithm used as the routing method. However, end-to-end delay increases which is not so vital unless a multimedia communication takes place. An alternative approach can be attaching a threshold mechanism to our method. In this approach, nodes apply Shortest Path routing method until they consume energy up to a critical threshold value. After the threshold level, energy-aware routing method (LEERA-MS) can be applied in order to choose the next hop. This approach (LEERA-TH) decreases the end-to-end-delay but it does not provide the energy efficiency supplied by LEERA.

In conclusion, there is always a trade-off between energy consumption and transmission time. For applications in which delay is not so vital, LEERA-MS provides the best performance in terms of lifetime of the network.

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