Statistical Verification and Validation of an Energy-Balanced Model for Data Transmission in Sensor Networks

Nalin Subramanian
Iowa State University

Arka Ghosh
Iowa State University, apghosh@iastate.edu

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Nalin V Subramanian
Department of Computer Science
Iowa State University
Ames, IA -50011
Email: {nvsubram}@iastate.edu

Arka Ghosh
Department of Statistics
Iowa State University
Ames, IA -50011
Email: {apghosh}@iastate.edu

Abstract

The problem of energy-balanced data transmission in sensor network is studied extensively in this paper. Energy Balance assures uniform energy dissipation among all the nodes in the sensor network. Uniform energy dissipation guarantees same average energy dissipation per node throughout the network. This enables the network to be fully functional for the maximum time, avoiding the early energy depletion of sensor nodes. Previously proposed models in the literature though theoretically proves the balance, we here propose a practical Energy-Balanced Transmission (Adaptive AODV) model which gives the required balance by transmitting packets as a combination of direct transmission to Base Station (an expensive) and multi-hop transmission towards Base Station (a cheaper), independent of routing protocol. In this paper the model is studied thoroughly, tested and simulated using ns2 simulator. Adaptive AODV is validated and analyzed through simulation results in reactive ad hoc routing protocols. The comparative results show the uniform energy utilization, and the flexible approach of the model.

I. INTRODUCTION

A Sensor Network consists of large amount of distributed sensors performing real time monitoring, communicating with each other in the wireless medium in an ad hoc fashion. Battery powered small inexpensive sensors have limited computational power. Saving energy and enduring the network life as long as possible are significant factors for design and implementation of wireless sensor network. Various transmission and clustering techniques has been proposed focusing towards this goal in the literature. Over usage of certain nodes were not explicitly focused by such techniques. In case of multi-hop packet transmission to a common base station, the nodes closer to the base station get over utilized. Perhaps, in case of direct transmission to the base station, the nodes far away from the base station tend to be utilized exhaustively. In either case certain nodes die early and let the network to disintegrate prematurely, although other nodes may have potential amount of energy left in it. In this paper, we propose practical Energy Balanced Transmission (Adaptive AODV) Algorithm for data transmission in wireless sensor network. We comparatively study, simulate and analyze the proposed balance models with regular routing protocol. The algorithm ensures network fairness in energy dissipation per node for any protocol. The energy utilization fairness throughout the network sensors prolongs network lifetime. Changing the data density at the receiving nodes makes the energy consumed evenly. The paper is organized as follows. Section II explains the related work and Section III explains briefly the assumptions used in the paper and discusses the main theory of the Adaptive AODV algorithm. Section IV details the simulation, results, analysis, discussion and comparison. Section V concludes the paper.

II. RELATED WORK

Undergoing revolution in Wireless Sensor Networks, which is made up of battery powered nodes empowered with a multitude of sensing modalities, promises to have a significant impact throughout society. Significant improvement and advancement in processor design, computing in battery technology still lag behind, making energy resource the major bottleneck in Wireless Sensor Network. Limited energy nodes are not taken into account in the traditional routing protocols, which has significant impact on the overall energy dissipation. There are protocols like table driven, on-demand for such network which follows direct transmission, minimum-transmission-energy, multi-hop routing, or static clustering. Optimal routing tries to maximize the duration over which the sensing task can be performed. There are various routing methods like multi-path routing, query based, hierarchical routing, hybrid routing, etc., in which optimal routing can be achieved in the context of energy. In this section, the focus is mainly driven over the related work study of the available routing protocol based on energy, and various routing methods proposed by researchers for even energy distribution for Wireless Sensor Network.

A. DATA CENTRIC PROTOCOLS

The two well known protocols [2][4] used in Data-centric methods are Sensor protocols for information via Negotiation and Directed diffusion. In SPIN, the data's are named using high level descriptors or meta-data. These meta-data are exchanged among sensors. There are three ways of messaging in SPIN. They are AODV message to advertise a particular meta-data by a sensor, REQ message to request the specific data, DATA message that carry the actual data. The advantage of the SPIN is that it gives 3.5 factors less than flooding in terms of energy dissipation and meta-data negotiation almost half the redundant data. The main method in Directed Diffusion is at diffusing data through sensor nodes by using a naming scheme for the data. This is to avoid the unnecessary operation in network layer in order to save energy. In order to form a query, an interest is broadcasted. The interest is defined by name of objects, interval, duration, geographical area, etc. The nodes receiving these data have the ability of network data integration, which is modeled as a minimum Steiner tree problem. . The advantage is that data centric is all communication is neighbor-to-neighbor with no need of addressing mechanism. Each node has the ability of doing aggregation and caching. This increases the energy efficiency and reduces the delay. There are different types of routing: Energy aware routing, Rumor routing, Gradient based Routing, Constrained anisotropic diffusion routing (CADR).Here only energy aware routing is discussed for understanding [2][5].

1) Energy Aware Routing: This method was proposed by Shah et al to increase the life time of the network. In this type of routing a set of sub-optimal paths is chosen by means of probability function, which depends on the energy consumption of each path. The approach argues that use of minimum path will lead to depletion of energy. Instead, one of the multiple paths is used with a certain probability so that the whole life time increases. The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes. There are 3 phases in the protocol: Setup phase, Data Communication Phase, Route maintenance phase. This method provides an overall improvement to increase the network life time.

B. HEIRACHIAL ROUTING

The main aim of hierarchical routing [1] is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Some of the hierarchical protocols are LEACH, PEGASIS, TEEN and APTEEN [5].

1) Low-Energy Adaptive Clustering Hierarchy (LEACH): This is one of the most popular hierarchical routing algorithms for sensor networks. In this a cluster of the sensor nodes is formed based on the received signal strength and use local cluster heads as routers to the sink. The energy will be saved since the transmissions will only be done by such cluster heads rather than all sensor nodes. LEACH [5] achieves over a factor of 7 reduction in energy dissipation compared to direct communication and a factor of 4-8 compared to the minimum transmission energy routing protocol. The nodes die randomly and dynamic clustering increases lifetime of the system.

2) Power-Efficient Gathering in Sensor Information Systems (PEGASIS): This is an extension of the LEACH protocol. Rather forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way.

3) TEEN and APTEEN: Threshold sensitive Energy Efficient sensor Network protocol (TEEN)[5] is a hierarchical protocol designed for the conditions like sudden changes in the sensed attributes such as temperature. The responsively is important for time-critical applications, in which the network is operated in a reactive mode. TEEN uses a data-centric method with hierarchical approach. The sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the sink is reached. The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) is an improvement to TEEN and aims at both capturing periodic data collections and reacting to time-critical events.

C. LOCATION BASED PROTOCOL

Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way.

1) MECN and SMECN: Minimum Energy Communication Network (MECN) maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile. A minimum power topology for stationary nodes including a master node is found. MECN assumes a master-site as the information sink, which is always the case for sensor networks. The small minimum energy communication network (SMECN) is an extension to MECN. The sub network constructed by SMECN for minimum energy relaying is provably smaller (in terms of number of edges) than the one constructed in MECN if broadcasts are able to reach to all nodes in a circular region around the broadcaster.

2) Geographic Adaptive Fidelity (GAF): This is an energy-aware location-based routing algorithm [4] designed primarily for mobile ad hoc networks, but may be applicable to sensor networks as well. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. It forms a virtual grid for the covered area. The energy is saved by keeping the nodes in a sleeping state.

3) GEAR (Geographic and Energy Aware Routing): This method [4] uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the sink. The idea is to restrict the number of interests in Directed Diffusion by only considering a certain region rather than sending the interests to the whole network. This protocol conserves more energy.

D. Comparison of Various Protocols and Current Issues

Unlike the wired network, there are lot of challenges and attraction in the routing for sensor network. The data routing in the sensor network are classified into three categories: data centric, location based, and hierarchical routing. In data centric approach, the name schemes are used for queries. Though this approach seems to be fine, this is not capable of handling complex queries. As the naming is application dependent, and if includes more complexity then adaptation is one the issue. The standardization of naming schema is another research issue. In the cluster based approach, the nodes are grouped and one with least energy is chosen as head. In this case we will be able to achieve efficient energy distribution and not even energy distribution. As we see, only a particular node gets focused on major operation and that node gets more consumed with energy than other. In the location based, the location information and topological deployment of sensor nodes are utilized. The number of energy-aware location-based approaches found here should have intelligent utilization of the location information in order to aid energy efficient routing is the main research issue. If no smart utilization is done then the consumption of energy in routing gets increased. Though we have seen lot of approaches have their own advantages and pitfalls, the basic assumption made here is that all the sensor nodes are fixed. But in the near future the usage of mobile sensor nodes and access to World Wide Web may happen. At that situation the successful routing methodology might not be capable of handling mobility and may fail. Basically the energy consumed by the nodes is mainly routing protocol and network topology. For different routing topology the routing protocol results with different energy consumption. Hence an adaptive protocol which can handle adapting topology might be well suitable for such situation and handles the mobility well. But this adds up much more computational complexity in the sense of processing. But as we see rapid advancement and development in the processor, this will not be a key constraint for such modification.

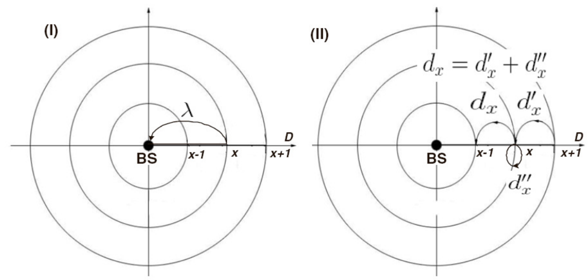
III. Theory of Adaptive Model

A. Model Assumptions

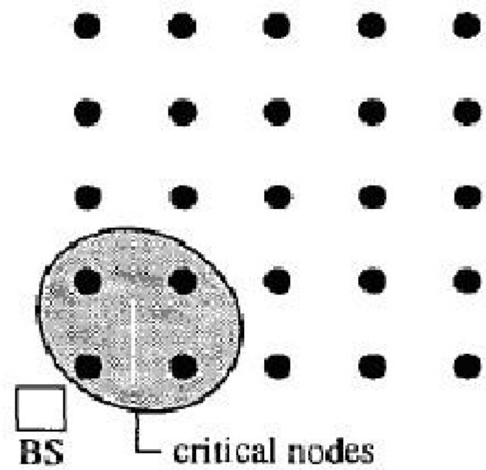
For our simulation, we assume fixed placement of sensor nodes in a grid fashion with the base station located in the center of the whole grid. We can also prove that our algorithm works the same way for mobile nodes. A constant data packet generation rate is assumed for all the nodes in a period of time. The base station is assumed to have sufficient energy to receive all the packets. The receiving energy will give the same effect as that of transmitting energy in algorithm analysis; proving that the algorithm works for transmission implicitly proves it works for receiving too.

B. Approach

In the data transmission in any wireless network there are two kind of strategies used, one, direct hop and another, multi hop to send data to the destination. We observed in both these strategies, that the energy consumption per node gets affected by the transmission distance and the data density parameters. By changing the data transmission range at each node, the data density gets modified accordingly. In case if we increase the transmission range, the data density gets reduced, similarly decreasing the transmission range, the data density gets increased at the intermediate nodes. This can also be observed in direct hop and multi hop transmission types. At each node with the data density k, we can send certain segments of the data density k directly to the Base Station by increasing the transmission range and power and the rest of the segment to Base Station via multi hop fashion. Consider a scenario in which the nodes having higher data density and are far away from the base station; the nodes can modify the transmission strategy to send fewer packets directly and large amount of packets through next hop intermediate nodes. On the contrary, if the node has very low data density the node can send larger data segments via direct hop and fewer via



(a) Transmission Protocols: (I) Direct Transmission; (II) Hop-To-Hop



(b) Critical Nodes in multi hop near Base Station

Fig. 1.

next hop. This reduces the total energy consumed by all the nodes and gives a balance among the energy utilization based on the data density. So by adjusting the ratio between direct and hop-by-hop transmissions at each node, we may get a constant curve of energy consumption rate across the network. In case of nodes having same data density this approach will show unfairness. In such scenario the inner layer nodes get over utilized as shown in figure 1(b). So in order to obtain fairness among all the nodes and maintain a balance along with the data density, the nodes have to take into consideration the network average energy. So based on the nodes energy utilization and the average network energy the node can modify the transmission pattern. In case, if a node is getting over utilized, the nodes energy utilization value shots higher than the network average energy. So at that situation the node can change the transmission pattern to next hop. In case, if a nodes energy value falls below the network expected average energy, then it can use direct hop mechanism in order to attain the expected network average value. By this way over a period of time, stability will occur in the energy utilization among the entire network and a balance of energy consumption will occur. To formulize the above approach, consider at each node 1 packet is to be transmitted to the Base Station (BS) at a time instance t. If the distance to its next hop is r_2, and distance to base station is r_1. Considering two dimensional space, if the node decide to transmit α amount of the packet directly to the base station and $(1-\alpha)$ packet segments to the next hop, then the energy consumed by the node for this packet is given by,

$$E = \alpha \times r_1^2 + (1-\alpha) \times r_2^2 - - - - - (i)$$

In the above equation, the total energy consumed is calculated as a sum of the energy consumed for multihop $((1-\alpha) \times r_2^2)$, and for direct hop $(\alpha \times r_1^2)$. Here each node consumes E energy per packet. To obtain the value of α for the transmission, say if the Expected average energy for the network is E_{exp}, and the node's current energy value is E_{cur}. Then in order to obtain the E_{exp}, the node have to either use next hop or direct hop for the variance,

$$\sigma = E_{exp} - E_{cur} - - - - - (ii)$$

The abve equation provides us the difference factor between the target energy value and presnt enrgy consumption. In order to attain Expected Energy E_{exp} the α value that should be used can be derived from the above equation (i),

$$\alpha = \frac{E_{exp} - r_1^2}{r_1^2 - r_2^2} - - - - - (iii)$$

However, the above equation gives the value of α just based on expected energy, and doesn't consider the current energy value of any node. Henceforth, using teh variance factor σ from the equation (ii), the equation (iii) can be rewritten as below,

$$\alpha = \frac{(E_{exp} + \sigma) - r_1^2}{r_1^2 - r_2^2} - - - - - (iv)$$

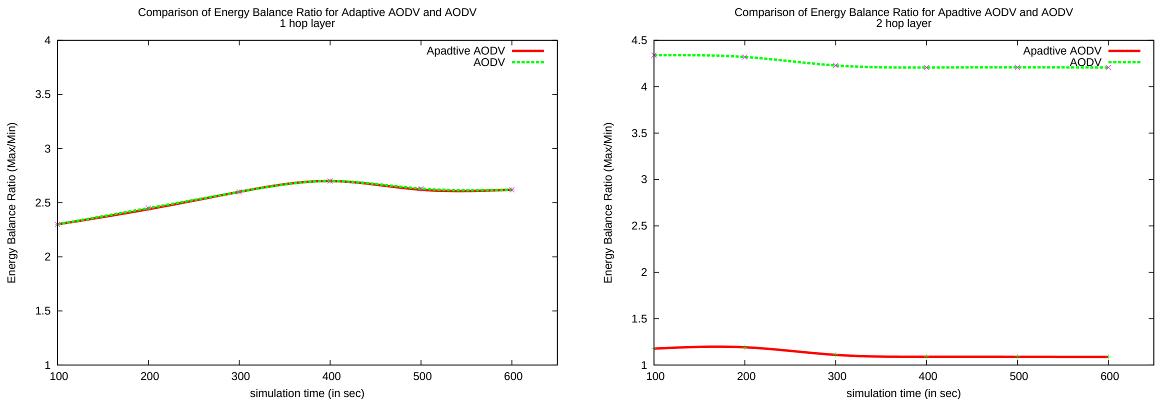
But at each node since we are also using hybrid multi hop-direct fashion for the data transmission, the nodes will not only consume energy for sending its own local packets but also for forwarding the received packets. So, the above equation (iv), should further be modified as below,

$$\alpha = \frac{\frac{(E_{exp} + \sigma) \times \rho}{\rho + \phi} - r_1^2}{r_1^2 - r_2^2} - - - - - (v)$$

where as, ρ - number of local Packets, ϕ - number of received Packets Here in the above equation (iv), the number of packets to be transmitted to base station is remodified in equation (v) to also include both local and received packets. By this way the amount of packets to be forwarded to base station and next hop is obtained. This way the energy balancing also considers the received packets dynamically at the runtime. This algorithm adapts to the data density and the network average energy and gets balanced accordingly. This algorithm is implemented in ns2 and the advantage of the algorithm is discussed in detail in the next section. Here we list few improvements that can be applied to our approach based on the application scenarios. The Basic approach of hybrid model of multi hop and direct hop though it gives greater improvement in the network lifetime, it wholly depends on the global information about the energy of all the nodes or the estimated value of the energy. In Sensor Network, the base station after obtaining the information it performs aggregated value on the all received data from all the nodes. The aggregation function is either sum, average, or some means of calculation on the whole data set received. Instead performing at the Base station, if the data aggregation is performed at the intermediate multi hop nodes and just the aggregated value is forwarded, this saves huge amount of energy. Second, improvement can be obtained by deploying heterogeneous devices. As the scalability factor is to be considered, in case of large scale sensor Network, if we rely completely on the sensor network forwarding it will become expensive compared to deploying some powerful heterogeneous communication devices for every cluster of nodes. This way, to forward the data's that got aggregated at the cluster, we can use the powerful communication devices. This way a large amount of energy and communication overhead can be greatly reduced. A notion of virtual base station can be introduced, which will be used in case of average energy per node get reduced below a threshold level. Third possible improvement would be, apart from the entire global energy for expected energy calculation, with the knowledge of neighboring nodes energy level alone before forwarding a weighted expected energy calculation will further improve energy balancing faster.

IV. Simulation Results and Discussion

The Simulation environment used for the testing is NS2. We used Wireless channel, in which nodes are distributed in a square grid fashion topology. The Base Station is located at the center of the grid. All the nodes are programmed

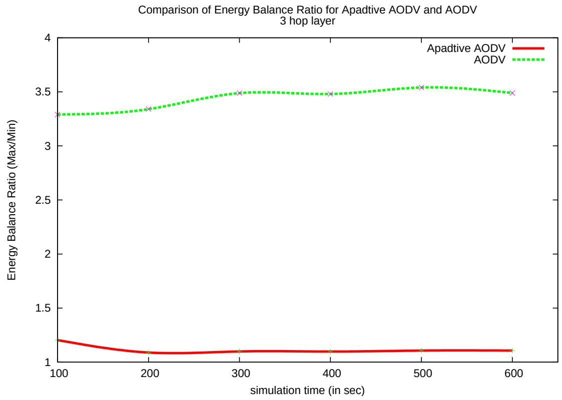


(a) Layer 1

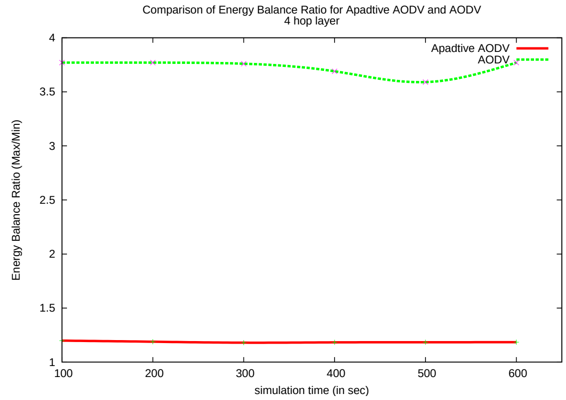
(b) Layer 2

Fig. 2.

with the base Station as its destination. Each node is separated by other node by a hop length of $150m$; the modification of the hop length to various values resulted in the same relative results leading to same conclusion. In majority of the Wireless Sensor Applications, most of the nodes are fixed. Only few of the nodes are intended to be mobile. Since our algorithm is independent of routing, the static and mobile nodes will perform the same way. Hence the nodes are assumed to be static in our simulation. For data transmission, it is assumed to generate data in a constant bit rate, one packet per node per second. For example at $300sec$, each node would have generated 300 local packets. This helps studying the performance of the simulation and algorithm better. The proposed Statistical algorithm performs the same way independent of the routing algorithm used for the Sensor Network Application Scenarios. To show the performance efficiency of the algorithm we have tested in the possible routing algorithms currently available. There are two classifications of Routing protocols in namely, proactive routing and reactive routing. In case of proactive routing, each an every node maintains a routing table information to all the nodes. This involves updating of routing information time to time among all the nodes throughout the network. The later classification is reactive routing protocol. In this protocol, the node request for the route only when it needs to send packets to other destination node. Here the node is required to just maintain the list of neighborhood nodes and not the global information. On request the route path is found and data transmission is processed using the newly found path. In our simulation, we took AODV routing protocol for reactive routing for implementing and studying the algorithm. The AODV Implementation was tested for both normal data transmission and Adaptive AODV data transmission in the above mentioned protocol. The results were mainly focused on the maximum, minimum, and average energy consumed by each node over a period of time. The simulation was done from 1 hop layer to 5 hop layers, for both the routing protocols. Also the simulation was done over various time frames (100s, 200s, 300s, 400s, 500s and 600s) to test the performance of the algorithm. The Simulation results were also tested for the fault tolerance of packet delivery at the Base Station for the both normal and Adaptive AODV data transmission. The reason for testing over more than 2 layers is that, just 2 hop layer energy analysis will not be sufficient enough to show the algorithm performed in large scale WSN. Since in just 2 hop layers, there is no possibility that the outer layer nodes to receive packets to perform hybrid transmission and to test for long run the energy utilization and network lifetime. So it is necessary to test more than 2 layers to get better proof of the algorithm. The various measurements taken are Maximum energy per node per local packet, Minimum energy per node per local packet, Whole network average energy consumed per node per local packet, total number of packets generated in the entire network, total packets delivered at the Base Station, Delivery Rate, and Ratio of max and min energy of the whole

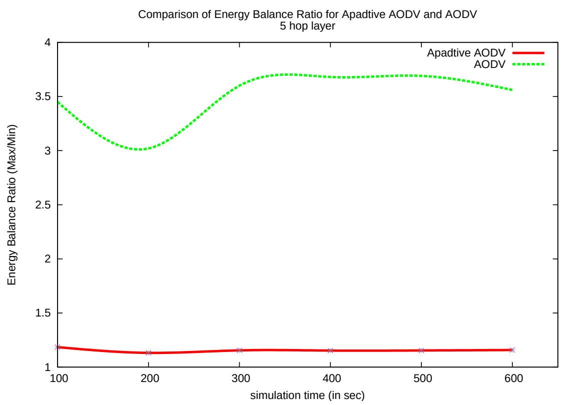


(a) Layer 3

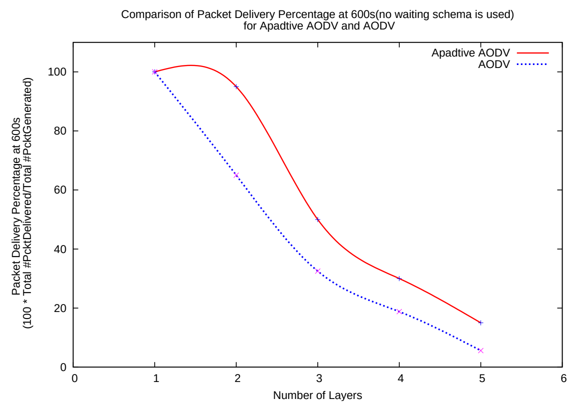


(b) Layer 4

Fig. 3.



(a) Layer 5



(b) Delivery Ratio

Fig. 4.

network per local packet. The ratio gives the variance of the energy in the whole network. This gives the energy balance parameter for the algorithm being simulated. This is the factor which decides the lifetime of the entire network. Closer the ratio to 1 greater increase in the balance of the energy of the network and lifetime, as the ratio moves away from 1, degradation of the network lifetime and the depletion of the network node happens faster in an unbalanced manner. Now we will analyze the results which we obtained in the simulation which we have plotted in the graphs. First we will show the performance of the Adaptive AODV algorithm for reactive routing protocol AODV (Fig.2-4). With AODV, we did both simulations for unmodified routing (AODV) and modified routing (Adaptive AODV) for one to five hop layers, and various measurements mentioned above were taken at 100s - 600s. Let us analyze the simulation result of AODV for the layer one. In this layer, there were only nodes which were located only one hop away from the base station. There were no nodes which were multi hop away from the base station. In the simulation of the grid fashion, the nodes at the corners are farther than the nodes located in the middle of the grid. This incurs more transmission energy per packet, which makes the energy not even between the nodes. This condition prevails throughout our discussion in all the layers for both Adaptive AODV version and AODV version. This was due to the underlying node deployment fashion and has same impact on both versions. We will show how our Adaptive AODV version improves the energy balancing even in such scenario, making the transmission dynamic as the number of layers increases. Hence for one hop layer in AODV (5), we see that the

simulation time (s)	AODV Max/Min Ratio	Adaptive AODV Max/Min Ratio	# layers	AODV Max Energy	Adaptive AODV Max Energy	AODV Min Energy	Adaptive AODV Min Energy	AODV Avg Energy	Adaptive AODV Avg Energy
100	2.3	2.3	1						
200	2.45	2.44	1						
300	2.6	2.6	1						
400	2.7	2.7	1						
500	2.63	2.62	1						
600	2.62	2.62	1	3.0233	3.02	1.1533	1.1521	2.62	1.5
100	4.34	1.1778	2						
200	4.32	1.192	2						
300	4.229	1.11	2						
400	4.207	1.09	2						
500	4.209	1.089	2						
600	4.2067	1.0877	2	6.31	3.1	1.5	2.85	3.02	3
100	3.29	1.204	3						
200	3.34	1.089	3						
300	3.488	1.099	3						
400	3.48	1.098	3						
500	3.54	1.107	3						
600	3.489	1.107	3	6.5	3.1	1.8633	2.81	4.1815	3
100	1.199	3.77	4						
200	1.189	3.77	4						
300	1.18	3.76	4						
400	1.183	3.69	4						
500	1.184	3.59	4						
600	1.185	3.77	4	5.4	3.2	1.43	2.7	3.5	2.95
100	3.45	1.185	5						
200	3.02	1.132	5						
300	3.6	1.155	5						
400	3.68	1.153	5						
500	3.69	1.154	5						
600	3.56	1.158	5	3.55	3.7	0.997	3.2	2.83	3.45

Fig. 5. AODV and Adaptive AODV Results Statistic

1layer	**AODV Ratio**	**Adaptive AODV Ratio**
100	2.3	2.3
200	2.45	2.44
300	2.6	2.6
400	2.7	2.7
500	2.63	2.62
600	2.62	2.62
t-Test: Paired Two Sample for Means		
1 Layer	*AODV*	*Adaptive AODV Ratio*
Mean	2.55	2.546666667
Variance	0.02176	0.021866667
Observations	6	6
Pearson Correlation	0.99939174	
Hypothesized Mean Difference	0	
df	5	
t Stat	1.58113883	
P(T<=t) one-tail	0.087343907	
t Critical one-tail	2.015049176	
P(T<=t) two-tail	0.174687813	
t Critical two-tail	2.570577635	
Since p-value > 0.05	**Ho is accepted**	

(a) Layer 1

Fig. 6. Hypothesis T-Test Results

ratio of the energy balancing for AODV version and Adaptive AODV version remains closely same for the periods 100s - 600s. Since our algorithm is a hybrid model of combination of both the direct hop and multi hop based on the energy, there will be no impact on the energy levels between AODV and Adaptive AODV versions. Since this is the case, we also observed the maximum, minimum and average energy per node per local packet was 3.0233, 1.1533 and 2.62 respectively for AODV version. For the performance of packet delivery ratio, the percentage of packet delivered to the base station is 100 percent for both the AODV and Adaptive AODV versions. We show this to understand in the later session that Adaptive AODV algorithm outperforms the AODV version for higher layers over a period of time. Now let us analyze the 2 hop layers of AODV. Here we have 24 nodes exclusive of Base Station. Total number of packets that will be generated every 100s is 2400 packets, since CBR is one packet per sec. Here for unmodified AODV version the maximum, minimum, average energy consumed per node per packet at 600s were 6.31, 1.15, 3.02 units. From this we observed that the energy balance gap that is the ratio was 4.2067 which is greater than 1, and this shows that the unmodified version will show an energy variance factor of 4.2067 among the nodes. This concludes in the 2 hop layers that the network lifetime is not balanced and the depletion factor is 4.2067. As shown in the table and graph, for modified Adaptive AODV version after a period of damping in the ratio it reaches a steady value (at the 600s) of 1.0877 with the maximum of 3.1 and minimum of 2.85. Though we can observe that the average energy of the entire network increases, the network life time tend towards balancing the depletion. This shows that the energy variation between the nodes either in outer layer or in the inner layer in the modified version gets reduced. This way we will be able to obtain a network balance in the

2 layer	**AODV Ratio**	**Adaptive AODV Ratio**
100	4.34	1.1778
200	4.32	1.192
300	4.229	1.11
400	4.207	1.09
500	4.209	1.089
600	4.2067	1.0877
t-Test: Paired Two Sample for Means		
2 Layer	*AODV Ratio*	*Adaptive AODV Ratio*
Mean	4.25195	1.124416667
Variance	0.003764615	0.002282418
Observations	6	6
Pearson Correlation	0.979769736	
Hypothesized Mean Difference	0	
df	5	
t Stat	440.0565465	
P(T<=t) one-tail	5.75052E-13	
t Critical one-tail	2.015049176	
P(T<=t) two-tail	1.1501E-12	
t Critical two-tail	2.570577635	
Since p-value << 0.05	**Ho is rejected**	

(a) Layer 2

Fig. 7. Hypothesis T-Test Results

energy and prolong the life time of the entire network. Now we will look at the graph for 3, 4, 5 layers. Here we can see that the ratio for the energy variation at 600s for unmodified AODV version were 3.488, 3.77, 3.56 units per node per packet. For the modified Adaptive AODV version the observed value were 1.107, 1.185, 1.155 for 3, 4, 5 hop layers respectively. This shows us that by the usage of combination of both direct hop and multi hop we obtain greater reduction in the variance between the maximum and minimum energy consumption. Comparative study for AODV protocol shows that usage of our Adaptive AODV algorithm reduces the variance ratio from 3.56 to 1.155. This is very close to 1, proving that usage of energy will be distributed in an equal and balanced fashion increasing the lifetime of the entire network. The above study with the simulated data shows that the average energy utilization of the entire network increases slightly from the unmodified AODV version of the protocol which is due to fact that Adaptive AODV tries to balance the maximum energy and minimum energy utilization in a equal way. This forms the basis for the fairness that Adaptive AODV is trying to obtain by the usage of Adaptive AODV algorithm. Though this increases the total energy the network lifetime increases greatly. Also we observed that the percentage of packet delivered at the Base Station for unmodified AODV version for 2, 3, 4, 5 hop layers were 65, 32.5, 18.8, 5.6 percent at the end of the 600s simulation (waiting for extended period after 600s, assured that the packet got delivered to the base station - which gives us the inference that AODV has greater end-to-end delay [12,15]). There is a greater degradation in the delivery as the number of layers increase. This is due to the fact that the packets generated at 600s, wouldn't have transmitted all the way to the inner layers as the layers increases (means that they are in the queue for transmission inside the network) and also there occurred high MAC layer

3 layer	**AODV Ratio**	**Adaptive AODV Ratio**
100	3.29	1.204
200	3.34	1.089
300	3.488	1.099
400	3.48	1.098
500	3.54	1.107
600	3.489	1.107
t-Test: Paired Two Sample for Means		
3 layer	*AODV Ratio*	*Adaptive AODV Ratio*
Mean	3.437833333	1.117333333
Variance	0.009755367	0.001847467
Observations	6	6
Pearson Correlation	-0.629383732	
Hypothesized Mean Difference	0	
df	5	
t Stat	43.6631061	
P(T<=t) one-tail	5.94652E-08	
t Critical one-tail	2.015049176	
P(T<=t) two-tail	1.1893E-07	
t Critical two-tail	2.570577635	
Since p-value << 0.05	**Ho is rejected**	

(a) Layer 3

Fig. 8. Hypothesis T-Test Results

congestion as the number of nodes increased. But, with modified Adaptive AODV approach due to the hybrid usage of direct hop and multi hop the inner layer nodes will not be flooded with same amount of packets as in unmodified AODV version, as the results obtained were 95, 50, 30, 15 percent for 2, 3, 4, and 5 hop layers. Compared to the unmodified AODV version, we can observe a greater increase in the percentage of the packets delivered to the base station. Due to the usage of Adaptive AODV algorithm the end-to-end delay for the packet delivery got highly reduced as observed with the packet delivery fraction (11). Along with all the above observation for AODV, we also observed that the unfairness between the corner nodes and other nodes in unmodified AODV version has been reduced comparatively. This means that the increase in energy utilization at the corner node will be smoothened fairly as the period of lifetime of the network increases. One would also argue that using multi hop over one hop has the advantage of reducing the MAC layer overhead and transmission energy consumption. But in Adaptive AODV approach it calculates the α factor based on the entire network energy utilization and dynamically changes the direct hop transmission factor. As per the results and the simulation we observed that the number of direct hop transmission to the base station is very low compared to the number of multi hop a node does over a period of time. The direct hop occurs very rarely, only when the energy in the network goes unbalanced and to make the energy utilization in a balanced manner. This proves that Adaptive AODV approach outperforms in energy aspect increasing the network lifetime and reduces the depletion of the network nodes compared to traditional approach for AODV protocol which holds the same advantage for other reactive protocols too.

4 layer	**AODV Ratio**	**Adaptive AODV Ratio**
100	1.199	3.77
200	1.189	3.77
300	1.18	3.76
400	1.183	3.69
500	1.184	3.59
600	1.185	3.77
t-Test: Paired Two Sample for Means		
4 layer	*AODV Ratio*	*Adaptive AODV Ratio*
Mean	1.186666667	3.725
Variance	4.50667E-05	0.00535
Observations	6	6
Pearson Correlation	0.342140647	
Hypothesized Mean Difference	0	
df	5	
t Stat	-87.415627	
P(T<=t) one-tail	1.85661E-09	
t Critical one-tail	2.015049176	
P(T<=t) two-tail	3.71321E-09	
t Critical two-tail	2.570577635	
Since p-value << 0.05	**Ho is rejected**	

(a) Layer 4

Fig. 9. Hypothesis T-Test Results

A. Hypothesis Testing $(T - Test)$

We further did hypothesis testing to show that there is a significant benefit of using Adaptive AODV over AODV protocol. The results of hypothesis testing are summarized in Tables 6(a)-10(a). We consider the Max/Min energy ratio of AODV and Adaptive AODV as two variable X, Y respectively. We define the hypothesis as below. Hypothesis H_0 states that the mean values of both the variables observed over various periods are equal ($\mu_X = \mu_Y$). Hypothesis H_1 states that the mean values of the variable X is greater than that of Y observed over various periods are equal ($\mu_X > \mu_Y$). We used the simulated data from the period 100s-600s to conduct the hypothesis testing between AODV and Adaptive AODV. We conducted the hypothesis t-testing for each layers (1-5layers) separately. We used 0.05 level of significance for all the t-test conducted. As we can observe from the t-test for layer one, the test proved the hypothesis H_0. This verifies our inference from the above section that the Max/Min Energy ratio for both AODV and Adaptive AODV remains same. However, as we tested for other layers, the hypothesis H_0 was rejected. Except for layer 1, the observed $p - value$ for all the t-test returned to be less than 0.05. Also, calculated $t - value$ is far less than the $t - critical$ value for all the layers except layer 1. This shows that the simulated energy balance results for Adaptive AODV got reduced from AODV proving the hypothesis H_1 for layers $2 - 5$. To summarize the simulation results the energy variance ratio between maximum and minimum energy utilization for reactive AODV routing protocol in the unmodified version gave 3.56 to 4.2067 which were reduced to 1.0877 to 1.158 by the usage of Adaptive AODV algorithm. Also the t-test results proves that the observation about the Adaptive algorithm is correct, and the difference in improvement of uniformity is significant. This concludes that

4 layer	**AODV Ratio**	**Adaptive AODV Ratio**
100	1.199	3.77
200	1.189	3.77
300	1.18	3.76
400	1.183	3.69
500	1.184	3.59
600	1.185	3.77
t-Test: Paired Two Sample for Means		
4 layer	*AODV Ratio*	*Adaptive AODV Ratio*
Mean	1.186666667	3.725
Variance	4.50667E-05	0.00535
Observations	6	6
Pearson Correlation	0.342140647	
Hypothesized Mean Difference	0	
df	5	
t Stat	-87.415627	
P(T<=t) one-tail	1.85661E-09	
t Critical one-tail	2.015049176	
P(T<=t) two-tail	3.71321E-09	
t Critical two-tail	2.570577635	
Since p-value << 0.05	**Ho is rejected**	

(a) Layer 5

Fig. 10. Hypothesis T-Test Results

# of nodes	**# of layers**	**total packets generated at 600 s**	**packets delivered at the Base Station for AODV**	**Packet Delivery %**
8	1	4800	4800	100
24	2	14400	9360	65
48	3	28800	9360	32.5
80	4	48000	9024	18.8
120	5	72000	4032	5.6
# of nodes	**# of layers**	**total packets generated at 600 s**	**packets delivered at the Base Station for AdaptiveAODV**	**Packet Delivery %**
8	1	4800	4800	100
24	2	14400	13680	95
48	3	28800	14400	50
80	4	48000	14400	30
120	5	72000	10800	15

Fig. 11. Packet Delivery Percentage at Base Station for $t = 600s$ for both AODV, and Adaptive AODV

Adaptive AODV algorithm outperforms for reactive routing protocol proving the validity of the algorithm by giving uniform energy dissipation.

V. Conclusions

This paper is the extended implementation and validation of the Adaptive Routing algorithm (Adaptive AODV) for energy balancing in Wireless Sensor Network using ns2. The main idea of the Adaptive AODV algorithm is that during multi hop data transmission to the Base Station, based on the network energy a fraction of packets are sent via direct hop and rest are sent via multi hop. The variation in usage of the multi hop and direct hop helps in reducing the variation between the energy utilization among the inner layer nodes and outer layer nodes. This results in fairness among the nodes and obtains a balance among the energy utilization. This increases the network lifetime. This idea is implemented in ns2 for reactive routing protocol proactive and results are tested using hypothesis t-test. The simulation results prove that the Adaptive AODV algorithm is independent of the routing protocol and outperforms the traditional approach.

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