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ENERGY EFFICIENT ROUTING IN WSNS BY USING THE TECHNIQUE OF MODELLING AND OPTIMIZATION

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Abstract- The applications of WSNs(Wireless Sensor Networks) is remote environmental monitoring and target tracking are important issues for detailed studies. The development of WSNs is based on their smaller size, less expensive and more intelligent in nature. The main features to be considered for the design of WSNs are its applications, environment, objectives of the applications, costs, necessary hardware and constraints. In this paper, a mathematical model has been proposed for a network design (routing protocol) in certain resource restrictions in WSNs. The distance between linking sensors and energy used by the sensors are two types of constraints in this proposed model. The aim of this proposed model is to find out the energy-efficient paths that minimize the use of energy between source sensor and the base station. The computational observations indicate the efficiency and applicability of proposed design. It can also apply to other WSNs design contexts having some possible resource restrictions or multi-level supply chain networks

Keywords: Wireless sensor networks, shortest path problem, multi-hop routing algorithm, cluster based algorithm, Data gathering sequence

I. INTRODUCTION

In recent years the researchers, have already paid their attention for the proliferation of MEMS(Micro-Electro-Mechnical System) technology to develop the smart sensors. The advantages of smart sensors compared to traditional ones are as following:
(i) Small size
(ii) limited processing
(iii) a few computing resources and
(iv) Inexpensive
These sensor nodes may sense, measure and collect information from the environment and then transmit them to each other through wireless communication channels under physical phenomenon on an older fashion. The designs of WSNs(Wireless Sensor Networks) are based on multi-hop(ad hoc) network technology. It organizes and maintains moving objects to communicate the information in a particular area where is no fixed access points or base stations. The multi-hop(ad-hop) network technologies have following properties:
(i) The construction of sensor networks.
(ii) The design and use of sensor networks.
(iii) The monitoring of stationary nodes.
(iv) The construction of buildings, bridges to reduce the consumption o power and overhead. The direct transmission is a simplest approach in WSNs. In the case, each node sends its own data directly to the sink. The cost of sending data directly to the base station situated far away is very large and the life of the nodes may be comparably less.
The military applications in battle field surveillance have motivated the developments and researches in WSNs. The WSNs have applications and uses in the following areas:
(i) industries and civilian purpose
(ii) industrial process monitoring and control

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(iii) machine health monitoring
(iv) habitat and environment monitoring
(v) health care applications
(vi) home automation
(vii) traffic control and
(viii) scientific exploration in dangerous circumstances tec.

The studies of the hop length are also important issues in WSNs while maintaining good energy efficiency and packet size optimization in BSNs(body sensors networks). The type of BSN(in-body or on-body) affects the optimal packet length for improving the energy efficiency in WSNs. Naturally, WSN is applied to detect the presence of vehicles ranging from motorcycles to trains, cars or other vehicles in the specific range of sensors.
The routing protocol specifies the following procedures:
(i) The communication of routes with each other.
(ii) In a computer network, dissemination of information to select the suitable route between any two nodes.
(iii) The execution of the selection of route via routing algorithm.

Each route is concerned with a priori knowledge of the networks which are directly connected to it. A routing protocol sends this information firstly to its nearest neighbors and then to complete networks. Thus, routers need the knowledge of the topology for the WSNs. The traditional ad hoc networks should not be used with sensor nodes if routing protocols are designed for data transfer. The sensor nodes have limited battery power. In this process, there is a consumption of more energy and power than the sensor nodes perform sensing and related computation operations. Hence, there is a need of developing the technique to consume the energy of nodes in the networks in case of routing query replies back to the sink node.
In case of minimum energy routing problem, there should be the optimization of the performance of a single user(an end-to-end connection) while the consumption of energy is minimum. By using a short path algorithm, this issue may be solved for wired networks. In this paper, the design of WSNs is to be considered which is quite different from the existing WSN design problem. In the existing WSN design problem, the shortest path has been observed in the given graph. But the objective of this paper is to find the shortest path between nodes and the energy. In this study, the mathematical models for the WSN design problem has been proposed. This problem includes distance and energy restrictions only.

II. MATHEMATICAL MODELS

The mathematical models for wireless sensor network have been designed under restrictions of resource. In details, there should be the maximum distance between the energy of the nodes and the linking nodes because sensors have limited available energy. A sensor the radio signal for connecting the other nodes. But it is found that the range of radio signal is small so it cannot reach long distances due to technical limitations. Sensors are self-organized and there is limitation of energy also. Due to this, each sensor is in the sleep mode as such it consumes minimum energy. At the time of happening of an event, the sensors comes in the wake-up mode and receives the information. After this, it reaches to other sensor for sending the information to the sink node (base station).

WSN models have the following requirements:
(i) several sensor nodes
(ii) a base station(a sink node)
(iii) source sensor node etc.
(iv) energy and linking distance (resource constraints) etc.
(v) the source sensor should reach the sink node.

The situation of sink does not change during the process of collecting data from the sensor nodes. The sensor nodes know

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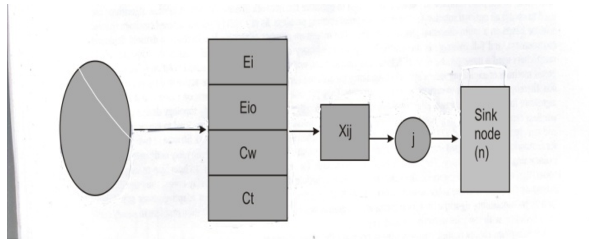


Figure 1: Schematization of the used notation

their geographical coordinates in the field of information. The energy and linking distance i.e. resource constraints affect each sensor but the sink node has no energy constraints. The notation used in the mathematical modeling has been schematized in fig(1).

2.1. WSN Model 1

WSN design modeling and the SPP(The shortest path problem) are similar. If a graph is given, the SPP model is used to find the shortest path within the range of possible distances between two nodes. The rate of consuming energy by a sensor is constant when it is connecting with another sensors. Here, the energy is in the stand by mode during the transmission of information. The levels of sensors are initially same. The transmission of energy in nodes is directly proportional to the distance between the sensors. In model 1, following limitations have been considered:

(i) the distance between nodes

(ii) the energy consumed during transmission.

The aim of model 1 is to avoid detection in a single period and it is applied to battlefield landmine as well as home security. The main objective of Model 1 is to minimize the sum of squares of the amounts of energy used. The notation is given below:

Indices

i, j, k	indices of nodes(i, j, k=1, 2, …, N)
N	number of nodes(i, j, k $\in$ N)
s	source node index
n	sink node index

Parameters

(1) Distance

d_{ij}	distance between node i to node j, $\forall i, j \in \mathrm{N}$
ld	maximum linking distance(constant)

(2) Energy

e_{io} initial energy of node i $\forall i \in \mathrm{N}$ ($e_{io} > 0$)

c_w energy consumed during sensor waken up(constant)

c_t rate of energy consumption during transmission(constant)

(3) Decision variable

X_{ij} 1, if node i and node j are linked;
0, otherwise, $\forall i, j \in \mathrm{N}$

E_i Energy of node i $\forall i \in \mathrm{N}$.

Model 1 is formulated in the form of following:

MILP(mixed integer linear program):

$$Min\left\{\sum_{i\in \mathrm{N}, i\neq n} e_{io}^2 - \sum_{i\in \mathrm{N}, i\neq n} E_i^2\right\} \tag{1.1}$$

subject to the constraints:

$$\sum_{i\in N, i\neq k} X_{ik}^2 - \sum_{j\in N, j\neq k} X_{kj}^2 = 0 \forall k \in N, k \neq s, k \neq n \quad (1.2)$$

$$X_{ij}^2 + X_{ji}^2 \leq 1 \forall i, j \in N, i \neq j \quad (1.3)$$

$$\sum_{j\in N, j\neq s} X_{sj}^2 = 1 \quad (1.4)$$

$$\sum_{j\in N, j\neq n} X_{jn}^2 = 1, \forall j \in N \quad (1.5)$$

$$d_{ij}^2 X_{ij}^2 \leq ld^2 \forall i, j \in N, i \neq j \quad (1.6)$$

$$E_i^2 - e_{io}^2 + c_w^2 \sum_{j\in N, i\neq j} X_{ij}^2 + c_t^2 \sum_{j\in N, i\neq j} d_{ij}^2 X_{ij}^2 = 0 \forall i \in N, j \neq n \quad (1.7)$$

$$X_{ij}^2 \in \{0,1\} \forall i, j \in N \quad (1.8)$$

$$E_i^2 \geq 0 \forall i \in N \quad (1.9)$$

Details of equations (1.1) to (1.9) are given below:

Equation No.	Detailed meaning
Eqn (1.1)	To minimize the sum of squares of the amounts of energy used by the nodes.
Eqn(1.2)	Flow conversational constraints when the total of squares of flow from node I to node j is equal to the total of flow from node j to node k except in the case of the source node s and sink node n.
Eqn(1.3)	Elimination of sub-tours.
Eqs(1.4) &(1.5)	Indication o flow out of source node s and into sink node n.
Eqn(1.6)	Limits on the squares of linking distance.
Eqn(1.7)	The remaining squares of energy of the node s.
Eqn(1.8)	The decision variable X_{ij} takes a value 0 and 1 only.
Eqn(1.9)	The values of decision variable E_i are non-negative.

2.2. WSN Model-2

In model-2, the multi-period has been considered to prolong the lifetime of WSNs. It is applied in the following sectors:
(i) industrial process monitoring,
(ii) control system
(iii) machine health monitoring
(iv) envoironmental system
(v) habitate monitoring.

Model-2 has been more objective i.e. multiple periods than model-1.
Some more notations are used in Model-2 i.e.,

Indices	detailed meaning
t	index of periods
T	set of periods($t \in T$)
$_e t$	end period index

Parameters

E_{io} initial energy of node $i \forall i \in \mathbb{N} \ (0 < E_{io})$

Decision variables

X_{ijt} 1, if node I ande node jare linked in period t;

0, otherwise, $\forall i, j \in \mathbb{N}, t \in T$

E_{it} energy of node i in period t, $\forall i \in \mathbb{N}, t \in T$.

WSN Model-2 is formulated in the form of following mixed integer linear program(MILP):

$$Min\left\{ \sum_{i \in \mathbb{N}, i \neq n} e_{io}^2 - \sum_{i \in \mathbb{N}, i \neq n} E_{i(et)}^2 \right\}$$

(2.1)

subject to the constraints:

$$\sum_{i \in \mathbb{N}, j \neq k} X_{ikt}^2 - \sum_{j \in \mathbb{N}, j \neq k} X_{kjt}^2 = 0 \forall k \in \mathbb{N}, t \in T, k \neq s, k \neq n$$

(2.2)

$$X_{ijt}^2 + X_{jit}^2 \leq 1 \forall i, j \in \mathbb{N}, i \neq j, t \in T$$

(2.3)

$$\sum_{j \in \mathbb{N}, j \neq s} X_{sjt}^2 = 1 \forall t \in T$$

(2.4)

$$\sum_{i \in \mathbb{N}, j \neq n} X_{\text{int}}^2 = 1, \forall j \in \mathbb{N} \ \forall t \in T$$

(2.5)

$$d_{ij}^2 X_{ijt}^2 \leq Id^2 \forall i, j \in \mathbb{N}, \forall t \in T$$

(2.6)

$$E_{it}^2 - E_{it-1}^2 + c_w^2 \sum_{j \in \mathbb{N}, i \neq j} X_{ijt}^2 + c_t^2 \sum_{j \in \mathrm{N}, i \neq j} d_{ij}^2 X_{ijt}^2 = 0 \forall j \in \mathbb{N}, i \neq j$$

(2.7)

$$X_{ij}^2 \in \{0,1\} \forall i, j \in \mathbb{N}$$

(2.8)

$$E_{it}^2 \geq 0 \forall i \in \mathbb{N}, \forall t \in T.$$

(2.9)

Objective function (2.1) minimizes the sum of square of total energy consumed at nodes by the end of all concerned periods.

Constraints from (2.2) to (2.9) are similar as used in WSN Model-1 except that the period index is considered in Model-2.

III. NUMERICAL EXAMPLES TO OBTAIN THE RESULTS

Number of selected nodes = 16.

Distance matrix from node i to node j(d_{ij})

j/i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	17	12	18	11	17	7	12	21	13	20	16	11	17	10	16
2	17	0	28	9	14	5	18	27	31	24	5	27	8	13	4	17
3	12	28	0	29	22	27	16	13	24	18	30	28	21	26	15	12
4	18	9	29	0	10	13	15	24	26	20	13	17	8	28	9	12
5	11	14	22	10	0	17	6	16	18	12	18	10	13	21	9	16
6	17	5	27	13	17	0	19	28	33	26	5	16	4	26	12	11
7	7	18	16	15	7	19	0	10	16	8	21	6	17	15	14	5
8	12	27	13	24	16	28	10	0	13	7	30	11	26	12	23	15
9	21	31	24	26	18	33	16	13	0	9	35	20	30	23	25	17
10	13	24	18	20	12	26	8	7	9	0	28	12	23	17	19	11
11	20	5	30	13	18	5	21	30	35	28	0	19	4	29	12	17
12	16	27	28	17	10	16	6	11	20	12	19	0	15	26	27	16
13	11	8	21	8	13	4	17	26	30	23	4	15	0	10	7	20
14	17	13	26	28	21	26	15	12	23	17	29	26	10	0	5	16
15	10	4	15	9	9	12	14	23	25	19	12	27	7	5	0	8
16	16	17	12	12	16	16	5	15	17	11	17	16	20	8	8	0

Table:1: Distance matrix from node i to node j d_{ij}

Models	Number of variables	Number of constraints	Average objective function value
1	272	572	9.12(27.6)
2	765	1570	125.13(28.13)

Table 2: Comprision results for models 1 and 2(average total distance)

Source node	Model 1	Model 2
Node 1	6.8(28) 2-6-3-11	30(150) -
Node 2	2.5(5) 3-11	8(30) -
Node 3	8.9(39) 4-6-1-3-11	51.8(231) -

Node 4	3.3(13) 5-11	15(70) -
Node 5	4.8-(18) 6-3-11	30.2(202) -
Node 6	2.5(5) 7-11	8(30) -
Node 7	6.4(24) 8-3-1-11	35.9(202) -
Node 8	7.2(33) 7-6-1-11	46.7(261) -
Node 9	8.8(44) 10-8-6-3-11	41.9(218) -
Node 10	6.7(29) 9-6-3-11	41.4(164) -
Sum	56.2(322)	263.7(2,198)

Table 3: Specific results for model 1 and 2 based on the numerical example sensor nodes nearby.

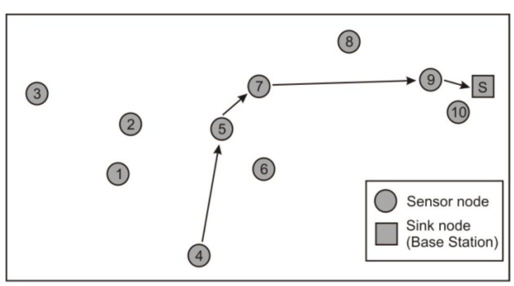


Figure 2: Optimal sensor network design in source node 3

	Total distance	Total consumed energy
Optimal network design(4-5-7-9-S)	40	9.6

Feasible network design 1(2-6-10-8-S)	42	10.2
Feasible network design 2(2-3-6-8-S)	44	10.4
Feasible network design 3(2-1-3-6-S)	44	10.4

Table 4:Comparison between networks in terms of total distance and energy consume by node 3

Fig(2) shows the graphical configuration for source node 3 in Model-1. In this network, the optimal to be charged for the source node-3 is linked with nodes 7, 5 and 2 to the sink node. The objective function value of this network is 7.8 and the total distance is 38. The energy consumptions figures for each node are given below:

Node	Energy consumed
3	2.5
7	1.6
5	2.3
2	1.4

The comparison between the optimal network and the feasible networks in respect of the total distance and total energy consumed is mentioned in Table-4.

IV. EXPERIMENTAL OBSERVATIONS

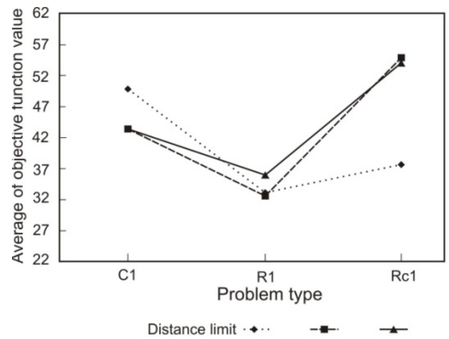
Using WSN Model 2, there is need of discussion to explore the applications of findings within WSN design having larger networks. The distance data for the sensors are taken from 150 customer problems of VRPTW Benchmark problems. A different subsets: R_1, R_2, R_3, R_{C1}, R_{C2}, R_{C3}, C_1, C_2 and C_3 are included in benchmark set. The customers are distributed randomly in R_1, R_2 and R_3 and clustered in C_1, C_2 and C_3. The clustered and random distributions are mixed in case of groups R_{C1}, R_{C2} and R_{C3}. Since x and y co-ordinates are identical for problems for each type of R, C and R_C therefore C_1, R_1 and R_{C1} problem types in the benchmark set are considered. The sink node is located atmost at the centre in all instances. The different parameters are required for test problems. The number o periods (T) is 10, 15 and 20 for C_1, R_1 and R_{C_1} respectively. Similarly, the distance limits (Id) are 10(10), 20 and 40. The limit of 10 has been used for R_1 and R_{C_1} tpes because distances between nodes of less than 10 are the rate for these types. The initial energy level ($e_{i\,o}$) of the sensors are 20, 30 and 40 respectively. In this experiment, 3600 problems are to be solved. Therefore, 10 source nodes are selected randomly and 360 problems are to be analyzed for a given number of periods T. The number of variables and constraints for the comparision of the test problems are mentioned in Table-5.

Number of Periods (T)	Number of Variables	Number of constraints
	C1/R1/RC1	C1/R1/RC1
10	56,511	108,516
15	108,017	211,026
20	159,518	313,536

Table 5: The number of variables and constraints for the comparison of the test problems.

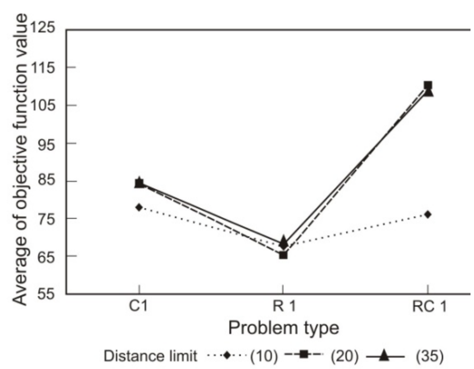
The results for the test problems are shown in Table-6. It is observed that objective function values differ with distance limit. The objective function value increases if the limit decreases. Following facts are observed by these results under tight limits:

(i) The next selected node is closer and
(ii) Several nodes are to be passed to reach the sink node.

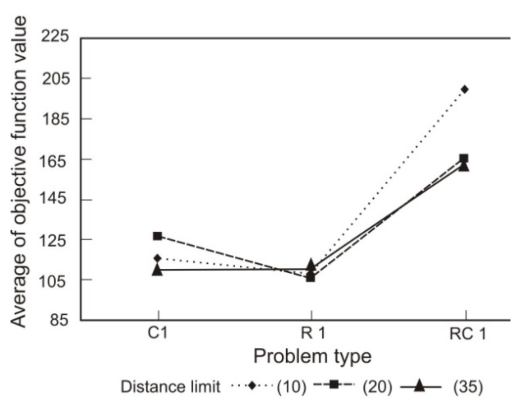


10 20 40

Figure 3: Comparision of the average objective function value for 10 periods.



Figue 4: Comparision of the average objective function value for 15 periods.



Figue 5: Comparision of the average objective function value for 20 periods

If the number of periods increases, the objective values concerned with distance limit of 20 and 40 are very different. It means that there are many nodes within a distance 20. For problem type, R_1(random) type has lower objective values than clustered C_1 and random clustered R_{C_1} types. Thus, either source node or sink node is introduced in the other cluster. The average objective function values for various periods are shown in Figs 3-5 graphically. The average objective function values for 10 periods are shown in Fig(3). It is found based on this figure that R_{C_1} type has the largest values and R_1 type has the smallest value. The average objective function values are shown in 15 periods. From figure (4), R_{C_1} is associated with the largest values and R_1 with

Number of periods	Distance limitation(ld)	Objective functional value								
		C1			R1			RC1		
		Average	Min.	Max	Average	Min.	Max.	Average	Min.	Max.
10	10	52.80	35.00	56.49	36.18	17.40	53.81	40.93	28.70	60.71
	20	46.30	28.40	50.00	35.56	17.40	52.15	58.13	30.09	69.104
	40	46.30	28.40	50.00	39.18	17.40	52.15	57.22	30.09	69.104
15	10	78.13	57.37	92.35	67.97	29.74	102.58	76.81	52.36	116.38
	20	84.61	55.07	93.102	65.69	29.74	98.75	110.95	55.13	137.07
	40	84.44	55.07	93.102	68.70	29.74	98.75	109.63	55.13	137.07
20	10	114.75	83.63	135.100	106.65	42.08	148.99	110.94	117.90	266.57
	20	126.09	80.17	130.89	105.15	42.08	146.35	165.83	99.20	203.08
	40	108.85	75.101	130.89	110.43	42.08	146.35	163.36	80.17	203.08

Table 6: Comparison of the results of the computational experiments.

the smallest values. These results are similar to 10 periods. The average objective function values in 20 periods are shown in fig 5. This fig 5 illustrates that again RC1 type has the largest values. However, the difference is quite small in these cases. From figs 3-5, it is observed that RC1 type has the largest objective function value and the difference is largest than in the 10-period and 20-period examples. When the number of periods increases the difference between the objective function values of R1 and C1 decreases and the difference between RC1 and R1 values increase. The difference between the objective function values concerned with R1 and C1 types decreases but the difference between RC1 and R1 values increases if the distance limit increases in both cases.

V. CONCLUSIONS

Following conclusions have been derived from this study:

(i) The wireless sensor network design has been considered under the restrictions of resorce.

(ii) Mathematical models have been developed for network design in which multiple periods as well as deistance and energy limits are considered.

(iii) The computation time is less than 10 s for each considered experiment.

(iv) The usefulness of the considered models are demonstrated by the computation experiments.

(v) The models of this study may be used in designing WSNs in real circumstances.

(vi) These mathematical models significant computational time. Hence, more time is needed for large scale WSNs.
(vii) There is a need of further research for developing a meta-heuristic for models which are in position to reduce the computation time as per our requirements.

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