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Energy efficient path determination in wireless sensor network by critical path method

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Abstract

Optimum use of energy of sensor nodes in wireless sensor networks (WSN) can maintain a prolonged network lifetime. The proposed concept is a typical tree-based aggregation scenario to optimise the energy level, for which a sensing device enables its transceiver to collect the results from its children. Using Critical Path Method (CPM) the proposed graph is derived as energy efficient in wireless sensor network. In order to establish the superiority of derived method, the early time and latest time of loss of energy of each node is calculated. The proposed method and graphs are derived using MATLAB.

Keywords

Wireless sensor network; WNS; data aggregation; binary tree; Critical Path Method.

AMS Subject Classification

26A33, 30E25, 34A12, 34A34, 34A37, 37C25, 45J05.

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Contents

1. Introduction

Wireless sensor network (WSN) is defined as a network of devices denoted as nodes that sense the environment and communicate the information gathered from the monitored field through wireless link [6]. These tiny sensor nodes, which consist of sensing, data processing and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes [7]. Sensor networks also introduce severe resource constraints due to their lack of data storage and power. Both of these represent major obstacles to the implementation of traditional computer energy efficient techniques in a WSN[14]. Energy consumption in WSNs is of paramount importance, which is demonstrated by the large number of algorithms, techniques and protocols that have been developed to save energy and extend the lifetime of the network[11, 14, 17] . The energy consumption for transmitting 1 bit of data using the MICA mote is approximately equivalent to processing $1,000$ CPU instructions [5, 10, 15, 16]. One way to cope with the energy challenge is to power down the radio transceiver during periods of inactivity. In particular, it has been shown that sensors operating at a two percentage duty cycle can achieve lifetimes of 6-month using two AA batteries [12].

The position of sensor nodes in WSN may not be engineered or pre-determined. Thetraditional networks aim to achieve high quality of service (QoS), so the provisions or protocols must focus primarily on power conservation [1–4]. They must have inbuilt trade-off mechanisms that give the end user the option of prolonging network lifetime at the cost of lower throughput or higher transmission delay [8, 9, 13]. The critical path method (CPM) is an optimal research technique of analysis to find the critical path, i.e., the sequence of activities with the minimum energy in wireless sensor node. CPM uses activity oriented network estimate with fair degree of accuracy and control both time and energy in network.

2. Proposed Methodology

Critical Path Method (CPM) is useful for planning, analyzing, controlling the progress and the completion of large and complex networks. To achieve these objectives, we take energy in place of time and carry out computations for:
1) Total energy needed for the completion of the network.
2) Categorization of the activities of the network as being critical or non-critical
An activity in a network diagram is said to be critical, if the delay in its start, will further delay the project completion energy. A non-critical activity allows some scheduling slack, so that the starting energy of the activity may be advanced or delayed within limits without affecting the completion of the entire network. The following factors are important to prepare a WSN:
a) Energy schedules for each activity i.e. the energy by which an activity must begin and the energy before which it is completed.
b) Maximum starting energy and minimum starting energy as well as maximum and minimum finish energy of each activity.
c) Float for each activity i.e. the spare energy associated with each activity.
d) Critical activities and critical path for the network.
For the purpose of calculation various energy of events and activities, following terms are used in critical path calculation:
E_i = Minimum/ Earliest starting energy of node i
L_j = Maximum/Latest starting energy of event j
e_{ij} = Energy of activity(i,j) i.e. energy required to transmit information from node i to node j
The critical path calculation is performed using the following two ways:
a) Forward Pass Calculation
b) Backward Pass Calculation

a) Forward Pass Calculation

Starting from the initial node $1(event1)$ with starting energy of the network as zero. Proceeding through the network visiting nodes in an increasing order of the node number and end at the final node of the network. At each node we calculate earliest start and finish energy for each activity, denoting Fi as the minimum/earliest occurrence energy at node i. The method may be summarized as:
Step 1. Set $E_1 = 0; i = 1$ (initial node)
Step 2. Set the earliest start energy for each activity that begins at node i as $ES_{ij} = E_i$;
for all activities (i, j) that start at node i.
Step 3. Compute the earliest finish energy of each activity that begins at node i by adding the earliest start energy of the activity to the duration of the activity. Thus

$$EF_{ij} = ES_{ij} + e_{ij} = E_i + e_{ij}$$

Step 4. Move on to next node, say node $j(j>i)$ and compute the earliest occurrence for node j.using
$E_j = Max(i)\{EF_{ij}\} = Max(j)\{E_i + e_{ij}\}$,
For all immediate predecessor activities.
Step 5. If $j = n$(final node), then the earliest finish energy for the project is given by
$E_n = Max\{EF_{ij}\} = Max\{E_{n-1} + e_{ij}\}$.

b) Backward Pass Calculation

We start from the final node n of the network. Proceed through the network visiting node of the decreasing order of node numbers and at the initial node l. At each node we calculate the least finish and start energy for each activity by considering $L_j$as the maximum/latest occurrence of node j. The method may be summarized as:
Step 1. $L_n = E_n; for j = n.$
Step 2. Set the latest finish energy of each activity that ends at node j as $LF_{ij} = L_j$.
Step 3. Compute the maximum/latest occurrence energy of all activities ending at$j$

$$LS_{ij} = LF_{ij} – e_{ij} = L_j – e_{ij}.$$

Step 4. Proceed backward to the node in the sequence , that decrease j by 1. Also compute the latest occurrence time of node $i(i<j)$ using

$$L_i = Min(j)\{LS_{ij}\} = Min(j)\{L_j - e_{ij}\}$$

For all immediate successive activities.
Step 5. If $j = 1$ (initial node), then

$$L_1 = Min\{LS_{ij}\} = Min\{L_2 - e_{ij}\}$$

Based on the above calculations, an activity (i,j) will be critical if it satisfies the following conditions
(i) $E_i = L_i and E_j = L_j$
(ii) $E_j – E_i = L_i – L_j = e_{ij}$
An activity that does not satisfy the above conditions is termed as non- critical

3. Algorithm for finding critical path method

We derived an algorithm for finding the critical path in a form of tree structure of sensor nodes in Wireless Sensor network:
For level 1 to 5
Generate node at N level = level (level+1)/2
Node ij where $i = 1$ to level and $j = 1$ to N level
Step 1 : To find the Maximum energy, calculate earliest start and finish energy

$$E_1 = 0, ij = 1, ES_{ij,k} = E_i$$
$$EF_{ij,k} = ES_{ij,k} + e_{ijk} = E_{ij} + e_{ij,k}$$

Step 2: For $(node(k>j))$

$$E_k = Max\{EF_{ij,k}\} = Max\{E_{ij} + e_{ij,k}\}$$

Step 3: If $k = 5$

$$E_5 = Max\{EF_{ij,k}\} = Max\{E_{5-1} + e_{ij,k}\}$$

Step 4: For find the minimum energy, we calculate least finish and start energy for each activity

$$L_5 = E_5 \text{ for } k = 5$$
$$LF_{ij,k} = L_k$$
$$LS_{ij,k} = LF_{ij,k} – e_{ij,k} = L_k – e_{ij,k}$$

Step 5: For $ij(ij<k)$

$$L_{ij} = Min(k)\{LS_{ij,k}\} = Min(k)\{L – e_{ij,k}\}$$

Step 6: For$k = 1$(initial node)

$$L_1 = Min\{LS_{ij,k}\} = Min\{L_2 – e_{ij,k}\}$$

Step 7: if

$$\{(\ E_{ij} = L_{ij} \text{ and } E_k = L_k)\ (E_k – E_{ij} = L_k – L_{ij} = e_{ij,k})\}$$

"PATH IS CRITICAL"
else "PATH IS NOT CRITICAL"

4. Problem Statements and Results

To establish energy efficient sensor nodes in wireless sensor network, the network is assumed as graph. For example, to find the minimum energy in graph with five nodes, there is a step by step process to find the minimum energy in graph using critical path method implemented in MATLAB.
Step -1: Development of graph which has five nodes, each node has energy different energy

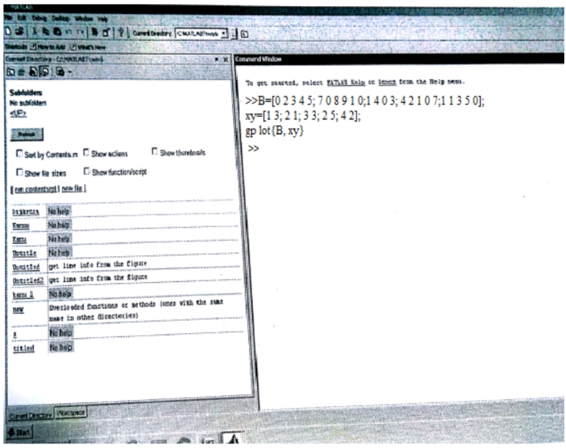

```
To get started, select MATLAB Help or Demos from the Help menu.

>>B=[0 2 3 4 5; 7 0 8 9 1 0;1 4 0 3; 4 2 1 0 7;1 1 3 5 0];
xy=[1 3; 2 1; 3 3; 2 5; 4 2];
gp lot{B, xy}
>>
```

Figure 1. Formation of five nodes to represent the graph .

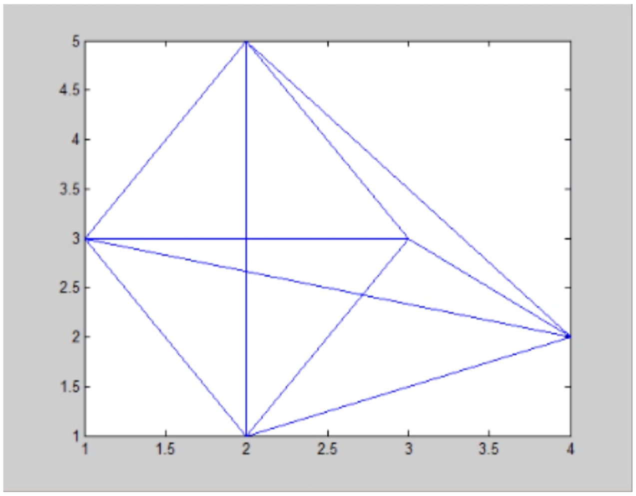


Figure 2. Each node has different energy .

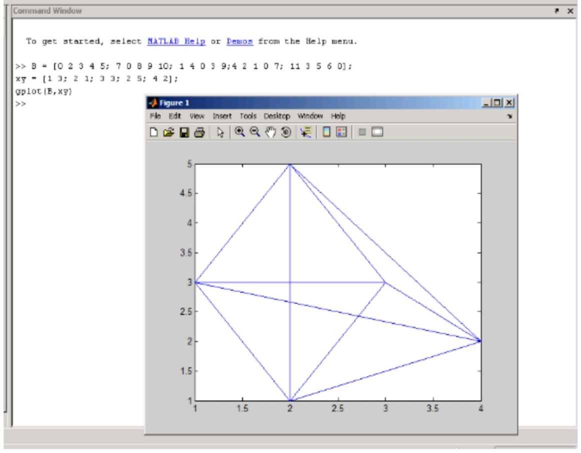

```
To get started, select MATLAB Help or Demos from the Help menu.

>> B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9;4 2 1 0 7; 11 3 5 6 0];
xy = [1 3; 2 1; 3 3; 2 5; 4 2];
gplot(B,xy)
>>
```

Figure 3. Representation coding and figure of graph(see online version for colours).

Step-2: Development of code for a graph of four nodes having different energies connected to a node with zero energy.

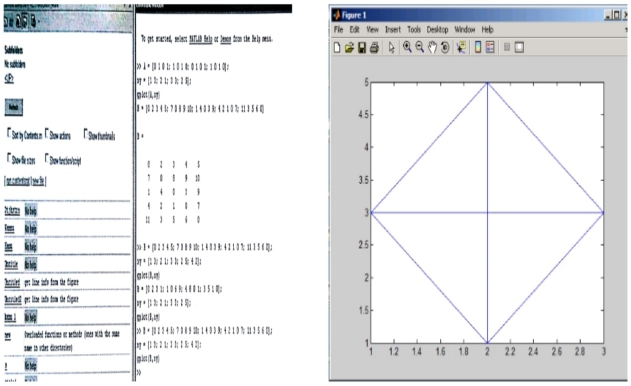
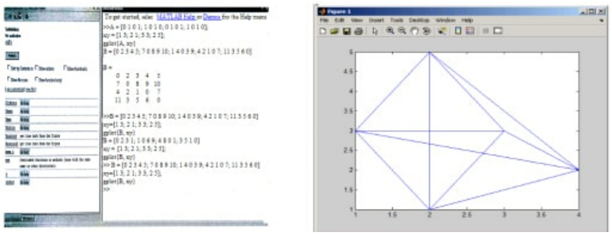

```
To get started, select MATLAB Help or Demos from the Help menu.

>> A = [0 1 0 1; 1 0 1 0; 0 1 0 1; 1 0 1 0];
xy = [1 3; 2 1; 3 3; 2 5];
gplot(A,xy)
B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0]

B =

     0     2     3     4     5
     7     0     8     9    10
     1     4     0     3     9
     4     2     1     0     7
    11     3     5     6     0

>> B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0];
xy = [1 3; 2 1; 3 3; 2 5; 4 2];
gplot(B,xy)
B = [0 2 3 1; 1 0 6 9; 4 8 0 1; 3 5 1 0];
xy = [1 3; 2 1; 3 3; 2 5];
gplot(B,xy)
>> B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0];
xy = [1 3; 2 1; 3 3; 2 5; 4 2];
gplot(B,xy)
>>
```

Figure 4. Representation of coding and figure of graph with four nodes (see online version for colours)

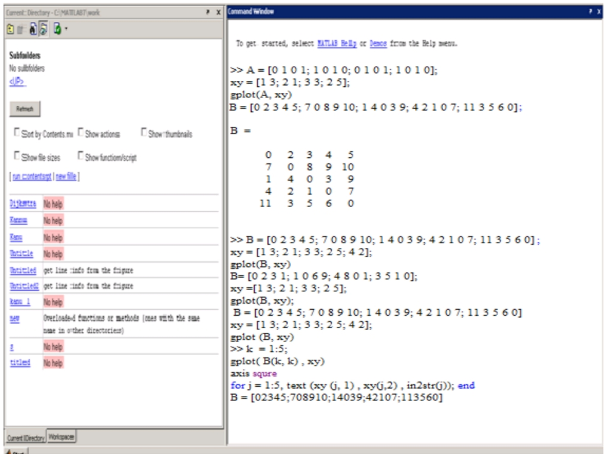
Step-3: Extension of graph for five nodes.



```
To get started, select MATLAB Help or Demos for the Help menu
>>A = [0 1 0 1; 1 0 1 0; 0 1 0 1; 1 0 1 0];
xy = [1 3; 2 1; 3 3; 2 5];
gplot(A, xy)
B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0]

B =
     0   2   3   4   5
     7   0   8   9  10
     4   2   1   0   7
    11   3   5   6   0

>>B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0]
xy=[1 3; 2 1; 3 3; 2 5];
gplot(B, xy)
B = [0 2 3 1; 1 0 6 9; 4 8 0 1; 3 5 1 0]
xy = [1 3; 2 1; 3 3; 2 5];
gplot(B, xy)
>> B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0]
xy=[1 3; 2 1; 3 3; 2 5];
gplot(B, xy)
>>
```

Figure 5 Representation coding and figure of graph(see online version for colours).

Step-4: Assign the weight of edges in graph and assesment of the critical path



```
To get started, select MATLAB Help or Demos from the Help menu.

>> A = [0 1 0 1; 1 0 1 0; 0 1 0 1; 1 0 1 0];
xy = [1 3; 2 1; 3 3; 2 5];
gplot(A, xy)
B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0];

B =

     0   2   3   4   5
     7   0   8   9  10
     1   4   0   3   9
     4   2   1   0   7
    11   3   5   6   0


>> B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0];
xy = [1 3; 2 1; 3 3; 2 5; 4 2];
gplot(B, xy)
B= [0 2 3 1; 1 0 6 9; 4 8 0 1; 3 5 1 0];
xy =[1 3; 2 1; 3 3; 2 5];
gplot(B, xy);
 B = [0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 11 3 5 6 0]
xy = [1 3; 2 1; 3 3; 2 5; 4 2];
gplot (B, xy)
>> k  = 1:5;
gplot( B(k, k) , xy)
axis squre
for j = 1:5, text (xy (j, 1) , xy(j,2) , in2str(j)); end
B = [02345;708910;14039;42107;113560]
```

Figure 6 . coding to assign the value of every node in graph(see online version for colours).

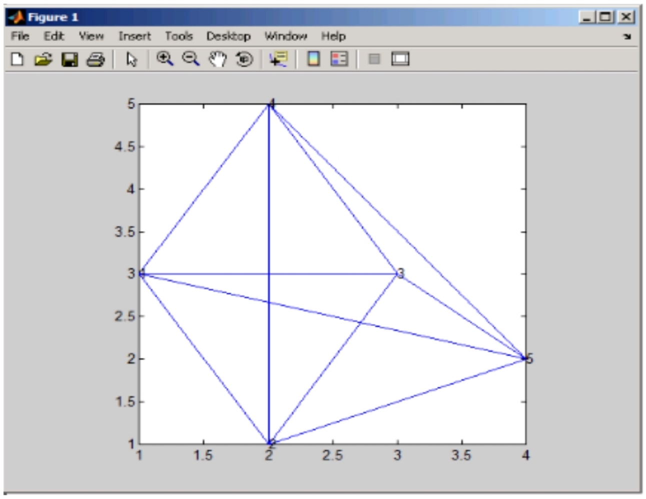
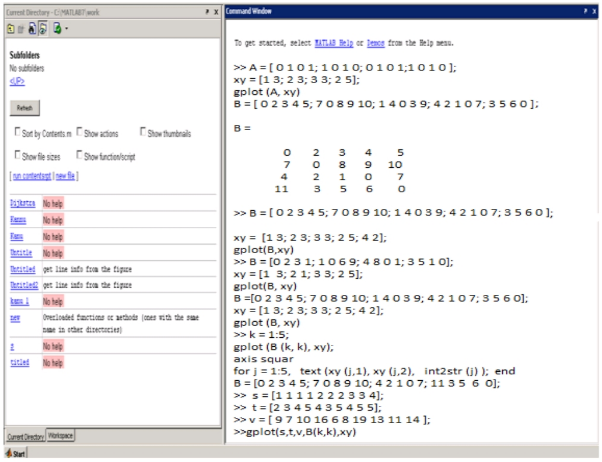


Figure 7 Representation of Coding to assign the value of every node in graph (see online version for colours).



```
To get started, select MATLAB Help or Demos from the Help menu.

>> A = [ 0 1 0 1; 1 0 1 0; 0 1 0 1;1 0 1 0 ];
xy = [1 3; 2 3; 3 3; 2 5];
gplot (A, xy)
B = [ 0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 3 5 6 0 ];

B =

         0    2    3    4     5
         7    0    8    9    10
         4    2    1    0     7
        11    3    5    6     0

>> B = [ 0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 3 5 6 0 ];

xy =  [1 3; 2 3; 3 3; 2 5; 4 2];
gplot(B,xy)
>> B = [0 2 3 1; 1 0 6 9; 4 8 0 1; 3 5 1 0];
xy = [1  3; 2 1; 3 3; 2 5];
gplot(B, xy)
B =[0 2 3 4 5; 7 0 8 9 10; 1 4 0 3 9; 4 2 1 0 7; 3 5 6 0];
xy = [1 3; 2 3; 3 3; 2 5; 4 2];
gplot (B, xy)
>> k = 1:5;
gplot (B (k, k), xy);
axis squar
for j = 1:5,   text (xy (j,1), xy (j,2),   int2str (j) ); end
B = [0 2 3 4 5; 7 0 8 9 10; 4 2 1 0 7; 11 3 5  6  0];
>>  s = [1 1 1 1 2 2 2 3 3 4];
>>  t = [2 3 4 5 4 3 5 4 5 5];
>> v = [ 9 7 10 16 6 8 19 13 11 14 ];
>>gplot(s,t,v,B(k,k),xy)
```

Figure 8 Coding to assign the weight to every edges in graph (see online version for colours).

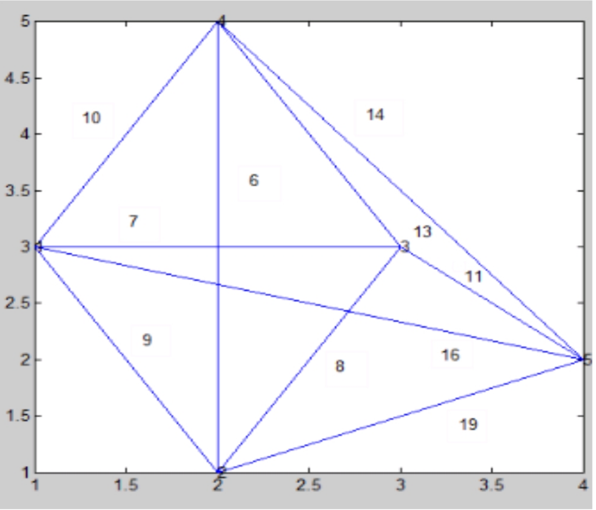


Figure 9 Representation of graph (see online version for colours).

Experimental Result for the problem

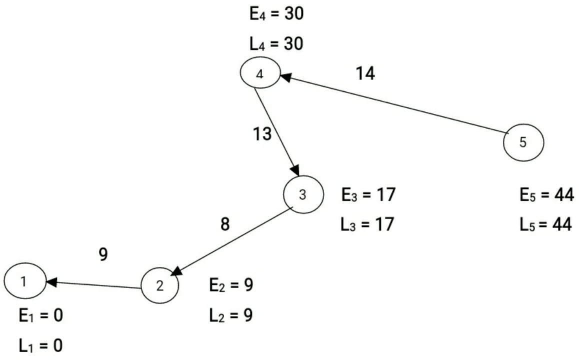
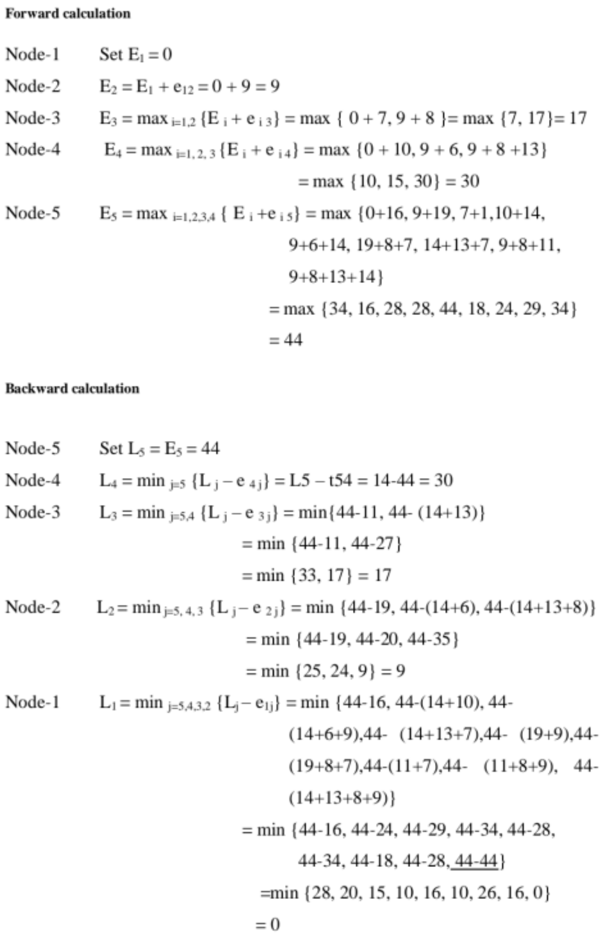


Figure 10 Resultant Critical Path for Energy Efficient graph (Minimization)



Forward calculation

Node-1 Set $E_1 = 0$

Node-2 $E_2 = E_1 + e_{12} = 0 + 9 = 9$

Node-3 $E_3 = \max_{i=1,2} \{E_i + e_{i3}\} = \max \{ 0 + 7, 9 + 8 \} = \max \{7, 17\} = 17$

Node-4 $E_4 = \max_{i=1,2,3} \{E_i + e_{i4}\} = \max \{0 + 10, 9 + 6, 9 + 8 + 13\}$
$= \max \{10, 15, 30\} = 30$

Node-5 $E_5 = \max_{i=1,2,3,4} \{ E_i + e_{i5}\} = \max \{0+16, 9+19, 7+1, 10+14,$
$9+6+14, 19+8+7, 14+13+7, 9+8+11,$
$9+8+13+14\}$
$= \max \{34, 16, 28, 28, 44, 18, 24, 29, 34\}$
$= 44$

Backward calculation

Node-5 Set $L_5 = E_5 = 44$

Node-4 $L_4 = \min_{j=5} \{L_j - e_{4j}\} = L5 - t54 = 14\text{-}44 = 30$

Node-3 $L_3 = \min_{j=5,4} \{L_j - e_{3j}\} = \min\{44\text{-}11, 44\text{-} (14+13)\}$
$= \min \{44\text{-}11, 44\text{-}27\}$
$= \min \{33, 17\} = 17$

Node-2 $L_2 = \min_{j=5,4,3} \{L_j - e_{2j}\} = \min \{44\text{-}19, 44\text{-}(14+6), 44\text{-}(14+13+8)\}$
$= \min \{44\text{-}19, 44\text{-}20, 44\text{-}35\}$
$= \min \{25, 24, 9\} = 9$

Node-1 $L_1 = \min_{j=5,4,3,2} \{L_j - e_{1j}\} = \min \{44\text{-}16, 44\text{-}(14+10), 44\text{-}$
$(14+6+9), 44\text{-} (14+13+7), 44\text{-} (19+9), 44\text{-}$
$(19+8+7), 44\text{-}(11+7), 44\text{-} (11+8+9), 44\text{-}$
$(14+13+8+9)\}$
$= \min \{44\text{-}16, 44\text{-}24, 44\text{-}29, 44\text{-}34, 44\text{-}28,$
$44\text{-}34, 44\text{-}18, 44\text{-}28, \underline{44\text{-}44}\}$
$= \min \{28, 20, 15, 10, 16, 10, 26, 16, 0\}$
$= 0$

Figure 11 Forward calculation and Backward calculation .

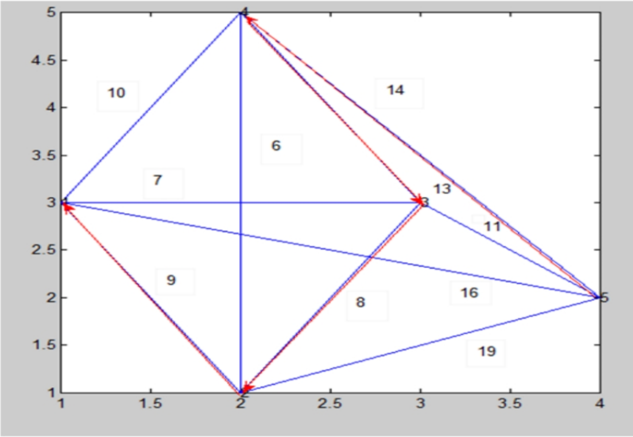


Figure 12 Resulting implemented figure of the energy efficient critical path for graph.

5. Conclusion

The present work is an attempt to minimize the energy in Wireless Sensor Network. The proposed problem statement for global best solution using critical path method in WSNs is implemented in MATLAB. A critical path is derived to show the minimum consumption of energy at source with earliest occurrence energy and latest occurrence energy in our problem statement.

The proposed method is implemented in two stages; first the concept of tree aggregation is proposed , in which a critical path for minimum energy consumption in WSN is developed and second is implementation of work with graph in MATLAB with adjacent matrix and assign the value at node and edges. Here a critical path with global solution to minimum energy at node from source to target with earlier and late time using CPM in WSN is calculated.

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