International Journal of Electronics Communication and Computer Engineering
Volume 5, Issue 3, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Ensuring Reliability of Backbone Architectures in Wireless Sensor Networks

Itu Snigdh
Department of Computer Science and Engineering
BIT Mesra, Ranchi, INDIA
Email: itusnigdh@bitmesra.ac.in

Aditya Kumar
Department of Computer Science and Engineering
BIT Mesra, Ranchi, INDIA
Email: email2kumaraditya@gmail.com

***Abstract* – Reliability of an event driven WSN application depends on the connectivity patterns of the network. The reliability of such networks is dependent on the successful delivery of the message. . Among other quality metrics, establishment of the final communication path becomes important. We try to estimate the reliability of backbone assisted networks against node failures attributed to energy depletion. Our algorithm ensures successful establishment of communicating paths with alternate parents to counter against node failures. It is seen that with the help of alternate parents that complete the broken path of communication, the overall reliability of the network increases, improving the fault tolerance of the links and the robustness of the architecture.**

***Keywords* – Wireless Sensor Network (WSN), Reliability, Lifetime, Alternate Parent List (APL), Optimal Alternate Parent (OAP), Hierarchical Model.**

I. Introduction

Reliability is one of the key metrics to determine the quality of a system. Over the past two decades there have been a number of studies on the reliability of hardware and software systems. As a result we have a number of analytical models that estimate reliability. Reliability of a network is essentially computed as the ability to establish connectivity under transient load and environmental conditions. WSN reliability differs from the conventional adhoc network reliability owing to constrained energy and computational resources of the devices establishing the network. Sensors are developed at low cost and are small in size and are typically expected to perform sensing, data processing and routing activities. Hence achieving longevity in unattended operations with the approved quality constraints become a concern. Applications that use sensor networks vary from event detection to environmental monitoring or hybrid applications; have different system and quality requirements. Our article focuses on the event detection based applications of sensor networks. Reliability of such type of networks is dependent on factors like the connectivity patterns (whether continuously connected, sporadic or intermittent) [1], or on the coverage constraints like (1-covered, K-covered) [2]. Reliability has also been conjunctly used with lifetime of such networks, in terms of First Node Dead, Half Node Dead, and Last Node Dead [3][4][5].

Literatures like [6] focus on the end to end reliability of backbone assisted WSN's. They perform a cost-benefit analysis on determining the number of gateway nodes to deploy for achieving the desired reliability. Similarly, GSPN [7] (Generalized stochastic petrinets) model is designed to evaluate the reliability of a parallel redundant fault tolerant WSN and claims to be more observable, scalable and portable than a Markov model. Factors affecting reliability have been extensively studied in context to the existing transport protocols in [8]. Our research is motivated by existing algorithms like ETC [9]; which propose use of alternate parents in tree based structures for balancing the workload and thus achieve the energy conservation and network longevity. Similarly, LEACH-SM [10] enhances the lifetime of nodes in comparison to the traditional LEACH with the help of efficient management of spares. But there has been no focus, to the best of our knowledge, on the reliability of such structures under an event detection scenario. We try to employ the concept of using spares in the form of alternate parents in our tree based hierarchy. Our approach uses passive spares to estimate and enhance the reliability of a tree based WSN.

II. Problem Formulation

We consider an event monitoring system with n relay stations (either parents or the consecutive alternate parents). Suppose a signal emitted from node 'i' can be received by both parent I and J and a signal relayed from parent I/J is received by both K and L iteratively.

Thus when parent I fails, the system is still able to communicate successfully via parent J. But if both I and J failed, the signal cannot be transmitted from 'i' to K or L and hence the system fails. Similarly, if any two consecutive stations in a system fail, the system fails. This is an example to a K out of N system, where K in this case is 2. More generally, a system with n components in a sequence is called a consecutive K out of n: F system.

III. System Model

Let V denote a set of n sensing devices $\{v_1, v_2 \ldots v_n\}$ in an Event driven wireless sensor network. Let $T = (V, E)$ denote the network tree that represents the communication edges E of the nodes in V. Assume that the nodes have a restricted communication range. In this case, a routing tree T is created connecting every node over a multi-hop path with the sink. The nodes are considered neighbors if they are within the communication range. Reliability is now estimated for such a tree based structure.

Consider an event driven wireless sensor network having nodes that are aware of their locations with respect to their randomly generated IDs. We consider the

International Journal of Electronics Communication and Computer Engineering
Volume 5, Issue 3, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

possibilities to calculate the communication reliability of the backbone structure subject to three types of failure:

1. Failure of the internal nodes except the root node
2. Failure of the leaf-parent link.
3. Failure of the link subject to root node failure or any link failure due to environmental conditions.

IV. Reliability Computation

Let an event be detected by 'n' nodes at different levels of a tree (of 'k' levels).the communication reliability of an event is dependent on the reliability of the node in terms of activeness of the node that is proportional to the residual energy of the nodes, the reliability of the link that is determined by the commutative probability of the activeness of the leaf parent consecutive pair. For simplicity, we assume that the route failure due to link disruption because of environmental conditions is negligible and hence the link and route reliability converge.

Reliability of the node (NR) =probability of activeness of the node= remaining energy of the node/ initial energy of the node. Since the activeness of a node 'i' does not depend on the activeness of node 'j' the probability is computed as independent events.

Communication probability of events (CR) = probability of sending of data from the sensed sensor to the base station.

$$CR = P(A_K).P(A_{K-1}/A_K).P(A_{K-2}/A_{K-1})\ldots P(A_1/A_2) \qquad (1)$$

Where $P(A_k)$is the probability of the activeness of the node at level 'k' and $P(A_{k-1} / A_k)$ is the conditional probability of activeness of node at level (k-1) subject to the condition that node at the K^{th} level is active. Since the node activeness is solely dependent on its own residual energy, $P(A_{k-1} /A_k)$ reduces to $P(A_{k-1})$.
Hence equation 1 becomes

$$P(A_k).P(A_{K-1}).P(A_{K-2})\ldots P(A_1) \qquad (2)$$

At layer 'k' if A_K is a parent of more than one nodes (say 'm') 'k+1'th layer nodes then

$$P(A_k) = P(P(A_{(k+1)_1}) \cup P(A_{(k+1)_2}) \cup \ldots \cup P(A_{(k+1)_m})) \qquad (3)$$

Table I: Notations used in algorithm

n	Number of nodes deployed
v	Starting vertex
cost[][]	Distance matrix
visited[]	Holds the vertices of the tree
parent[]	Holds the parent of each nodes
alt_parent[][]	Holds all the alternate parents of each and every nodes
opt_alt_parent[]	Holds the optimal alternate parent of each nodes
level[]	Denotes the level of each nodes
q[]	Maintains the queue for BFS
sensing_range	Sensing range of the nodes
number[]	Counter for the total number of alternate parent for each nodes
V_T	Holds vertices of MST during its construction
d[v]	Holds the weight of the edge from any vertex in V_T to vertex v

A. Algorithm used

```
/* Optimal alternate parent */
1.  Procedure Optimal_alt_parent(n, sensing_range,
    parent[], level[], opt_alt_parent[], cost[][],
    alt_parent[][])
2.  //Let v is the starting vertex so visited[v] = 1 and
    level[v] = 1
3.  // Parent and level of each node is calculated and Tree
    is constructed using either BFS_Parent_Level or
    MST_Parent_Level.
4.  begin
5.    for i = 0 to n do
6.      begin
7.        min= 0;
8.        flag_chech= 0;
9.        for j=0 to n do
10.         begin
11.           if j!=parent[i] and i!=parent[j] and cost[i][j]!=0
    and cost[i][j]<=sensing_range
12.             alt_parent[i][min]=j;
13.             min++;
14.             flag_check=1;
15.         End if
16.       End for;
17.       if flag_check = 0
18.         alt_parent[i][min]=-1;
19.         min++;
20.       End if;
21.       number[i]=min;
22.     End for;
23.     for i = 0 to n do
24.       begin
25.         min= sensing_range;
26.         flag_check = 0;
27.         for j= 0 to number[i] do
28.           begin
29.             if level[alt_parent[i][j]]<level[i] and
    min>=cost[i][alt_parent[i][j]]
30.               opt_alt_parent[i]=alt_parent[i][j];
31.         flag_check=1;
32.             End if;
33.         End for;
34.         if flag_check = 0
35.           for j= 0 to number[i] do
36.             begin
37.               if min>=cost[i][alt_parent[i][j]]
38.                 opt_alt_parent[i]=alt_parent[i][j];
39.           min=cost[i][alt_parent[i][j]];
40.               End if;
41.             End for;
42.           End if;
43.     End for;
44.   End Optimal_alt_parent;
```

```
/* BFS_Parent_Level */
Procedure BFS_Parent_Level(cost[][], n, v, visited[], flag_b[], parent[], q[], level[])
//Global f = 0 , r1 = -1;
begin
  i = 0;
  while i< n
    if cost(v, i) != 0 and visited[i] = 0 and flag_b[i] = 0 then
      q[++r1] = i;
      flag_b[i] = 1;
      parent[i] = v;
      level[i] = level[v] + 1;
    End while
  if f <= r1 then
    visited[q[f]] = 1;
    v= q[f++];
    BFS_Parent_Level(cost[][], n, v, visited[], flag_b[], parent[], q[], level[]);
End BFS_Parent_Level
```

```
/* MST_Parent_Level */
Procedure MST_Parent_Level(cost[][], n, r, visited[], parent[], level[])
begin
  VT = {r};
  d[r] = 0;
  for all v ϵ (V – VT) do
    if edge (r, v) exists set d[v] = cost(r, v);
    else set d[v] = ∞;
  while VT != V do
  begin
    Find a vertex u such that d[u] = min{d[v] | v □ (V – VT)};
    VT = VT U {u};
    parent[u] = v for which d[u] = min{d[v] | v □ (V – VT)};
    level[u] = level[parent[u]] + 1;
    For all v □ (V – VT) do
      d[v] = min{d[v], cost(u, v)};
  End while
End MST_parent_level
```

The above algorithms describe the way to find out the optimal alternate parent of nodes. Initially a tree is constructed and parent & level of each node are determined using either MST_Parent_Level or BFS_Parent_Level algorithms.

The MST_Parent_Level algorithm begins with selecting a starting vertex denoted by the sink. It then grows the minimum spanning tree by choosing a new vertex and edge that are guaranteed to be in a spanning tree of minimum cost (which is defined in terms of the Euclidean distance). At the same time parent and level of each selected nodes are assigned and stored.

The BFS_Parent_Level algorithm starts at a vertex v; ideally the sink and labeled as it as having been visited. The vertex v is at this time said to be unexplored. A vertex is said to be explored when all vertices adjacent from it are visited. All unvisited vertices adjacent from v are visited next. These form the set of new unexplored vertices. Vertex v is now claimed to have been explored. The newly visited vertices haven't been explored as yet and are put onto the end of a list of unexplored vertices. The first vertex on this list is the next to be explored. Exploration continues until no unexplored vertex is left in an iterative manner.

The Optimal_alt_parent algorithm is used to find the optimal alternate parent of nodes. Here, the optimality is decided by choosing the node on the following constraints:

- Node which is in communication range.
- Node should not be the parent itself.
- Node should not be the child of the node.
- If there exists any node which is in communication range of the selected node and belongs to the upper level of the tree. If no such node exists then we can go for siblings but there is a chance that the tree may become forest.
- If two or more node fulfils the criteria for optimality then choose the one with low cost.

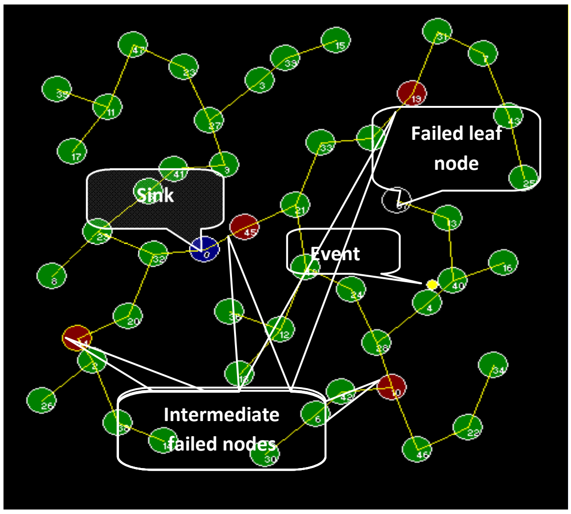

Fig.1. Scenario depicting failures

According to above fig. 1 an event 'E' occurs at a point p(x=78, y=58), which is in the sensing range of the sensor nodes 4, 13, 16, 24, 28, 37 and 40. But 37 is inactive node so it will not able to detect the event. Now 13 and 16 are active and they will transmit the information to their parent i.e. node 40 which have also detected the same event.

Let probability of activeness of node 13 and 16 is $P(A_{13})$ and $P(A_{16})$ respectively, determined by equation 1. The communication reliability up to node 40 is given by $R(E_{40}) = P(A_{40}) \cup P(A_{40}) * P(A_{13}) \cup P(A_{40}) * P(A_{16})$ from equation 2 and 3. Our aim is to communicate the information to the sink which is in our case is 'S_0'. Now again node S_{40} will send this information to its parent i.e. node S_4 which have also detected this event. This time the communication reliability up to node 4 is computed as $R(E_4)= P(A_4) \cup P(A_4) * R(E_{40})$. Similarly, $R(E_{28}) = P(A_{28}) \cup P(A_{28}) * R(E_4)$ and $R(E_{24}) = P(A_{24}) \cup P(A_{24})*R(E_{28})$ can be computed further. At this juncture, the parent of node S_{24} is node S_{48} which has not detected the event; so the communication reliability of event is given by $R(E_{48}) = P(A_{48}) * R(E_{24})$ as per equation 4. In the same way $R(E_{21})$

$= P(A_{21}) * R(E_{48})$. We now observe that the parent of node S_{21} is node S_{45} which is dead, so node S_{21} chooses an alternate parent which is node S_9. Hence, the information is sent to node S_9 and reliability is calculated as below:

$R(E_9) = P(A_9) * R(E_{21})$

$R(E_{41}) = P(A_{41}) * R(E_9)$

$R(E_5) = P(A_5) * R(E_{41})$

$R(E_{29}) = P(A_{29}) * R(E_5)$

$R(E_{32}) = P(A_{32}) * R(E_{29})$

So the final communication reliability of event E is

$R(E_0) = P(A_0) * R(E_{32})$

V. Results

The Algorithms are compared on their performance on the basis of delivery ratio of the reports of events. The delivery ratio is computed as the ratio of total number of messages received at the sink over the total number of messages generated by the nodes detecting the event. This is further computed over 500 events sampled over a total of 5000 events iteratively. The factor that determines the failure of node is solely dependent on the energy expedited by the nodes due to the transmission and reception of messages. The depletion of the node energy is also determined by the probability that the event is detected by the node and is purely random following a Poisson's distribution. We use first order radio model [11] to calculate the energy consumption of the nodes.

A. BFS Based tree architecture

From the Following fig. 2(a), 2(b), 2(c) we observe that on an average, the percentage of nodes that are able to find available route to the sink is more for APL based communication. Out of 5000 events, computed iteratively over a sample size of 500 cumulative events; the algorithm involving alternate parents yields a successful delivery ratio to nearly 1 for node failures ranging from 1node to 5nodes.

Fig. 2(d) illustrates the cumulative number of events that were able to reach the sink via some alternative route. We see that the performance of our algorithm with APL is better than the BFS used without APL.

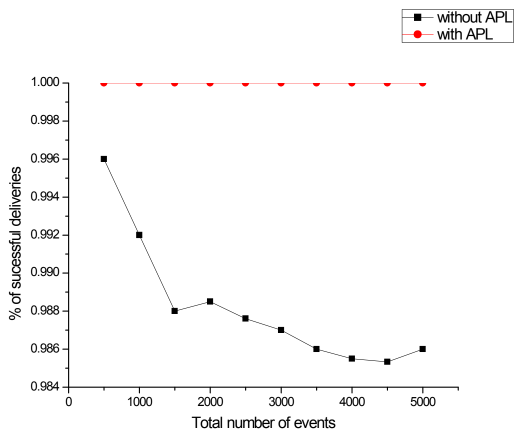

Fig.2. (a): Two nodes failed (1 child, 1parent)

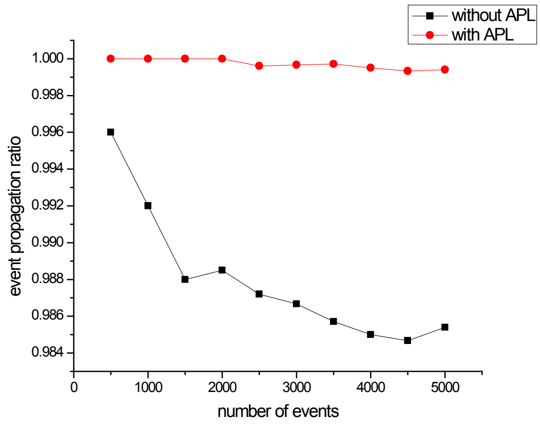

Fig.2. (b): Three/ four nodes fail (1 child, 3/4 parents)

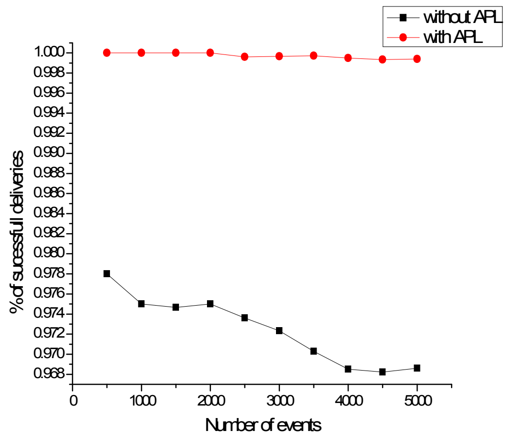

Fig.2. (c): Five nodes fail (1 child, 4 parents)

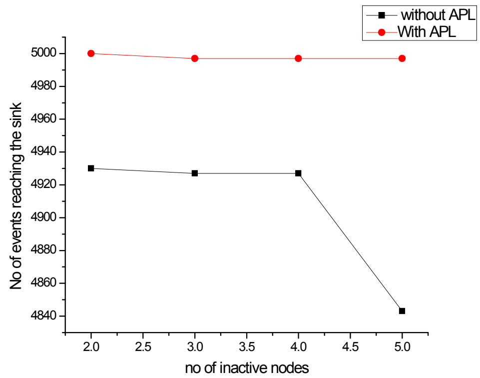

Fig.2. (d): Total no of delivered events Vs no of failed nodes

VI. Conclusion

The Wireless communication usually follows graph based architecture. This is due to the robustness achieved in terms of successful deliveries. But the amount of redundant transmissions increases the possibility of faster depletion of energy of the nodes. Also, the contention for resources increases manifold. For WSN, that need to essentially use a hierarchical or tree based architecture, our

International Journal of Electronics Communication and Computer Engineering
Volume 5, Issue 3, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

algorithm brings in the desirable robustness. From the above discussion we justify that if we employ alternate parents to the existing tree based communication architectures, reliability increases. Hence, in event detection applications that need to be based on a hierarchy as a constraint, our algorithm stands a better chance by enhancing the performance of the existing and usually employed algorithms.

REFERENCES

[1] A. Ghosh and S.K. Das, "Coverage and Connectivity Issues in Wireless Sensor Networks," *Mobile, Wireless and Sensor Networks: Technology, Applications and Future Directions.* John Wiley &, Sons, Inc. Mar. 2006.

[2] S. Soro and W. Heinzelman, "Prolonging the Lifetime of Wireless Sensor Networks via Unequal Clustering," *Proc. 19th Int',l Parallel and Distributed Processing Symp. (IPDPS ',05),* Apr. 2005.

[3] A. Giridhar and P. R. Kumar "Towards a theory of in-network computation in wireless sensor networks", *IEEE Commun. Mag.*, vol. 44, pp. 98 -107 2006

[4] Lee M, Wong V. LPT for data aggregation in wireless sensor networks. Proceedings of IEEE Globecom, St. Louis, Missouri, December 2005.

[5] C. Derman, G. J. Lieberman, and S. M. Ross, "On the consecutive k -out-of-n:F system", IEEE Trans. Reliability, vol. R-31, pp.57 -63 1982.

[6] Ali Tufail, Syed Ali Khayam, Amna Ali, Fatima Muhammad Anwar, Waleed Akram, Ki-Hyung Kim, Seung-Wha Yoo, " On the Reliability of Backbone-Assisted End-to-End Transmissions in WSNs" IEEE, ICUFN International Conference , June 2009.

[7] Nan Yao, Shaoping Wang, Yaoxing Shang , Jian Shi, "Reliability of Wireless Sensor Network: Hotspot and Critical Challenges" 2012 IEEE.

[8] Dhanashri .N wategaonkar, vivek S deshpande, "Characterization of reliability in wsn" - 2012 IEEE *World Congress on Information and Communication Technologies.*

[9] P. Andreou, A. Pamboris, D. Zeinalipour-Yazti, P.K. Chrysanthis, G. Samaras, "ETC: Energy-driven Tree Construction in Wireless Sensor Networks", Tenth International Conference on Mobile Data Management: Systems, Services and Middleware, 2009 Page(s):513 – 518.

[10] B. Abu Bakr and L. Lilien, Extending Wireless Sensor Network Lifetime in the LEACH-SM Protocol by Spare Selection. Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), PP: 277-282,2011.

[11] Zusheng Zhang, Fengqi Yu, "Performance Analysis of Cluster-Based and Tree-Based Routing Protocols for Wireless Sensor Networks", International conference on communication and mobile computing, IEEE, pp: 418-422, 2010.

AUTHOR'S PROFILE

Itu Snigdh

received her Masters Degree (Software Engg.) from B.I.T Mesra(Ranchi) and her Bachelor's Degree in Electrical Engineering from BIT Sindri.. She is currently working as an Asst. Professor in the Department of Computer Science and Engineering at BIT Mesra and also pursuing her Ph.D from the same Institute in the area of Wireless sensor networks. Her areas of interest include software Eng, Database Mgmt. Systems and Wireless Sensor Networks.

Aditya Kumar

he received his B.Sc. Degree in Mathematics from the S. K. University, Dumka and the Master of Computer Application from the Vellore Institute of Technology, Vellore. He is currently pursuing his M.Tech in the Department of Computer Science from Birla Institute of Technology, MESRA, Ranchi under the guidance of Prof. Itu Snigdh. His area of interest is wireless sensor networks.