Global Journal of Computer Science and Technology
Network, Web & Security
Volume 13 Issue 13 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 0975-4172 & Print ISSN: 0975-4350

# Reliable and Energy Saving Multipath Routing in Multisink Wireless Sensor Networks

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*GJCST-E Classification :* *C.2.1*

RELIABLE AND ENERGY SAVING MULTIPATH ROUTING IN MULTISINK WIRELESS SENSOR NETWORKS

*Strictly as per the compliance and regulations of:*

# Reliable and Energy Saving Multipath Routing in Multisink Wireless Sensor Networks

Raminder Singh Uppal [α], Dr. Shakti Kumar [σ] & Dr. Harbhajan Singh [ρ]

*Abstract* - In wireless sensor networks (WSN), the single path routing may result in path failure during data transmission and re-establishment of alternate path might take more duration. Also, using architecture with single sink node can cause issues of energy dissipation and poor channel condition. In order to overcome these issues, in this paper, we propose a reliable and energy saving multipath routing in multisink wireless sensor networks. The proposed architecture contains multiple sink nodes and neighbors of sink nodes are considered to be representative nodes which are in one hop distance. Initially, each node constructs neighbor and representative node table based on the parameters such as residual energy, transmission success rate and hop count of the nodes. When the node wants to transmit the data from source to destination, it establishes the multiple optimal paths for data transmission based on link weight estimate based on the parameters such as energy level and transmission success rate stored in neighbor table. By simulation results, we show that the proposed approach minimizes the energy consumption and link failures.

*Keywords : wireless sensor network, multipath routing, multi sink nodes, energy consumption.*

## I. Introduction

### *a) Wireless Sensor Network*

Wireless Sensor network (WSN) is a network of many tiny battery powered sensor nodes deployed in area of interest for monitoring physical environments. Nodes integrate sensing units, transceiver and actuators with limited on-board processing and radio capabilities. [1]

Radio is implemented on nodes of wireless communication to transfer the sensed data from node to base station which can be an access point to fixed infrastructure computing device like laptops etc. [2] The data accumulated at the base station provides dense sensing close to physical phenomena of the environment to be used by the user. [3]

There are certain constraints in the field of WSN namely low memory of the sensors, limited energy availability and reduced processing power. Still WSN application has spread into various multi-disciplinary fields. These fields can be categorized into environment monitoring in marine , soil and atmospheric context, seismic and flood detection, meteorological or geophysical research[4], battlefield surveillance, vehicle and object tracking. [5,6] In health applications WSN provides integrated patient monitoring ,diagnostics and drug administration in hospital. [7,8] Smart environment and automation of home [9], office buildings environmental control[10], Vehicle tracking and detection [11], natural disaster relief[12] and agriculture.[13]

Routing of sensed data from the environmental to base station under the constraints of WSN is the primary channel. Routing in sensor networks is different from contemporary communication and wireless ad-hoc networks. Numbers of sensor nodes are deployed in the area to be sensed and data collected from these nodes is forwarded to sink node by inter-node wireless multi-hop communication. Performance of routing protocols depends upon the architecture model of the network i.e. sensor nodes, sink and events to be sensed from the environment. The data sensed by sensor node from environment are to be routed to the sink in energy efficient mode in order to increase the lifetime of the network.[14]

Thus routing protocols of wireless sensor network are designed to communicate sensed data to single sink in energy efficient way to maximize life time. Like in the application of habitat monitoring sensed environment data from multiple sensor nodes is collected in a single sink.[15]. Researchers are investigating the networks to collect data at multiple sink as it results in less energy consumption[16]. Like in the case of fire scenarios emergency signal are sensed and also water sprinklers are controlled by sensed temperature by the same sensor nodes.[17] Single path routing and multiple path routing are different types of wireless sensor network routing. Even though single path routing is scalable but due to the resource constraints of WSN it is not efficient in present scenarios of research.[18]

### *b) Limitations of Single Path Routing*

In single-path routing, for each data packet, there is only one copy traveling along one path in the network. [19] Even though single path routing is simple and consumes less energy, it has more drawbacks when compare with multipath routing. Some of the drawbacks are described below,

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Generally, in a single path routing, routing failure will cause a break of transmission and hence completely ruin the delivery. [19]

The low flexibility of this approach against node or link failures may significantly reduce the network performance in critical situations. [20]

The success probability provided by single path routing is very low. [19]

Whenever the active path fails to transmit data packets (as a result of limited power supply of the sensor nodes, high dynamics of wireless links and physical damages), finding an alternative path to continue data transmission process may cause extra overhead and delay in data delivery. [20]

Therefore, due to the resource constraints of the sensor nodes and the unreliability of wireless links, single-path routing approaches cannot be considered effective techniques to meet the performance demands of various applications. [20]

*c) Limitations of Single Sink in sensor networks*

In WSN architecture, sensor nodes are interconnected via multi hop wireless links to a single sink responsible for relaying sensed data to a central control station. [21] Single sink architecture has more limitations such as,

The data transmission in single-sink sensor networks usually only considers the number of hops and the total energy consumption from the source nodes to the sink. The routing path is the nearest path and may include nodes with less energy remaining and large energy consumption for data transmission. These routing paths cannot guarantee the maximum lifetime of the networks. [22]

The commonly adopted single-sink architecture, be it static or mobile, is extremely vulnerable to poor channel conditions, especially when it occurs anywhere enroute to the sink, or worse, at the vicinity of the sink. [23]

In sensor network, the distance from each sensor node to a sink (except one-hop neighbor nodes of the sink) is larger than the transmission range of sensor nodes; sensor nodes should transmit their data packet to the sink in a multi-hop manner. Therefore, sensor nodes near the sink tend to dissipate their energy faster than nodes located far away from the sink because they have to forward a large number of data. [24]

*d) Routing in multipath and multi-sink scenarios*

Multipath routing is adopted to provide alternative paths for data to be delivered in order to increase the probability of successful delivery. To minimize the chances of the multiple paths approaching one another and contending for the shared wireless channel, the paths diverge like a starburst towards multiple sinks deployed along the edges of the sensor network. [23]

In a multi-sink network, the sinks act as gateways forwarding sensed data towards the storage systems network. Each sink collects the data generated only by a subset of devices and the overall monitored phenomenon is reconstructed at the data storage system. Multisink networks can remarkably reduce the mean distance between nodes and sink, resulting in energy saving and longer lifetime. [25]

*e) Previous Work*

In our previous work, [26] we have presented an adaptive energy saving and reliable routing protocol (AESRR) for wireless sensor networks. In AESRR, sensor node reduces its maximum transmission range in order to reach the extreme neighbor for saving energy before sending the first packet. The route discovery process of AESRR is on-demand. In the route discovery process, a combined link weight is determined based on the parameters transmission success ratio and node's residual energy. The best route is selected based on this link weight value. The sensor node must readjust the transmission range when remaining energy reaches bellow a threshold link weight value. Our proposed protocol saves energy, and prolongs the lifetime of node while enhancing the reliability.

## II. Related Work

Hongseok Yooet al. [24] have introduced a new gradient-based routing protocol for LOad-BALancing (GLOBAL) in large-scale WSNs with multiple sinks. Their protocol assumes that network lifetime is defined as the time elapsed from the deployment to the instant when one of sensor nodes becomes dead; the network lifetime is limited by the lifetime of the most over-loaded sensor node. Therefore, their routing protocol should be able to prevent sensor nodes from using a path including the most overloaded sensor node. In their GLOBAL protocol, in order to allow a sensor node to use the least-loaded path, which also avoids the most overloaded sensor node, each sensor node calculates its gradient using the weighted average (WA) of the cumulative path load and traffic load of the most overloaded node over the path.

Luca Mottola et al. [27] have presented a MUlti-Source MUlti-Sink Trees for Energy-efficient Routing (MUSTER), which is expressly designed for many-to-many communication. First, they have designed an analytical model to compute, in a centralized manner, the optimal solution to the problem of simultaneously routing from multiple sources to multiple sinks. Their MUSTER starts with independently built trees. As nearby nodes simultaneously funnel traffic, it progressively changes the shape of different trees in a fully decentralized fashion, based on knowledge on paths in the 1-hop neighborhood. This information is compactly encoded and piggybacked on every outgoing message, allowing a node to learn about the availability of better routes and possibly switch parent. Local changes made by a node typically trigger a ripple effect that causes the nodes ahead on the same route to change their parent as well. Nevertheless, in absence of simultaneous traffic in nearby regions of the network, MUSTER still behaves as standard collection protocols.

Pietro Ciciriello et al. [28] have addressed the problem of efficiently routing data from multiple sources to multiple sinks. The author's goal is to support efficiently many-to-many communication from multiple sources to multiple sinks. First, they have studied the problem from a theoretical standpoint, by mapping it to the multi-commodity network design problem. From this theoretical standpoint, they have derived an optimal solution that, albeit based on global knowledge and provides a theoretical lower bound to evaluate decentralized solutions against it. Then, they have proposed own decentralized scheme, based on a periodic adaptation of the message routes aimed at minimizing the number of network links exploited. Their protocol is simple and easily implementable on WSN devices.

Haiyang Liu et al. [29] have proposed a novel framework referred as PWave, which is to support multisource, multi-sink any cast routing that is inherent in WSNs. Their PWave constructs a potential field by assigning a "potential" to each node: a source or an intermediate node routes traffic (proportionally) to neighboring nodes with lower potentials towards the sinks, which have the lowest (zero) potentials. Their PWave framework is designed with strong theoretical underpinnings. They have developed a fully distributed algorithm for constructing the potential field and implement PWave using probabilistic forwarding to achieve the properties described above. PWave scales to the density of the network because only one-hop neighborhood information exchange is needed. In addition, this algorithm is resilient to network dynamics in that local perturbations only have local effect. These features make Pwave a suitable routing framework for WSNs.

Chunping Wang et al. [30] have introduced a Load Balance Routing Algorithm for Multi-Sink wireless sensor networks (MSLBR). They have introduced MSLBR to balance the load among the neighbors of all sink nodes and enhance the lifetime time of Multisink wireless sensor networks. In their MSLBR, the packet generated by the same sensor node can traverse different paths to different deputies each time so that the loads can be balanced and the network lifetime is prolonged. In addition, both nodes' shortest communication hops to a sink and the energy level of the node's neighbor are used to find its packets next hop during the routing procedure.

Preetha Thulasiraman et al. [31] have developed a distributed algorithm to compute two node-disjoint paths to two distinct drains in a network employing |D| drains. First, they have proved that a two-vertex-connected network is sufficient to construct |D| trees such that every node has at least two paths (on two trees) that are node disjoint. Based on this they have constructed |D| pairs of colored trees. Every node selects the tree pair that provides the shortest path cost. The packets in the network are routed using the drain address and one additional bit. They have formulated the problem of constructing |D| tree pairs that minimizes the average length of the two paths for all the nodes as an integer linear program (ILP) and develop a distributed algorithm that has a time complexity O(|D||L|) to construct the trees.

## III. Problem Identification and Solution

### *a) Overview*

In this paper, we propose multipath, multisink routing mechanism in wireless sensor networks. The proposed architecture contains multiple sink nodes and neighbors of sink nodes are considered to be representative nodes which are in one hop distance. Initially, each node constructs neighbor and representative table. The neighbor table contains neighbor node id, residual energy of neighbor nodes and transmission success rate. The representative table comprise of Representative id, hop count and next hop. When the node wants to transmit the data from source to destination, it establishes the multiple optimal paths for data transmission based on link weight estimated based on the parameters such as energy level and transmission success rate obtained in the neighbor and representative table.

### *b) Estimation of Metrics*

i. *Estimation of Residual Energy*

The residual energy (Eres) of each node (Ni) after performing one data communication is estimated using following formula. It is defined as the difference between the initial energy and energy utilized during transmission and reception of data. [32]

$$Eres = Ei - (Etx + Erx) \quad (1)$$

Where Ei = Initial energy of the node

Etx & Erx = energy utilized at the time of transmission and reception of data.

ii. *Estimation of Transmission Success Rate*

The transmission success rate (SRtx) represents the probability that a node correctly delivers data to the destination. SRtx can be calculated by the following equations.

Let SRtxi denote the Transmission success rate of a node Ni.

The value of SRtxi is initially set to zero and updated whenever there is message transmission or timer expiration. Whenever a node Ni transmits a data packet to another node Nj, SRtxi need to be updated such that

$$SRtxi = SRtxi + \alpha * SRtxj, 0 < \alpha < 1, 0 < SRtxi < 1 \quad (2)$$

Where SRtxj is the transmission success rate of node Nj and $\alpha$ is a constant employed to keep partial memory of historic status.

If Nj is the destination

Then

SRtxj = 1 (since the message has already been delivered to the destination successfully)

Else

$$SRtxj < 1$$

End if

Each node maintains a timer T1. If there is no message transmission within an interval of x, then the timer T1 expires. The timer expiration indicates that the node couldn't transmit any data during x.

So SRtxi should be updated as

$$SRtxi = (1 - \alpha) SRtxi \quad (3)$$

So from (2) and (3), we arrive that, the SRtxi of Ni is updated as

SRtxi = SRtxi + $\alpha$ SRtxj, if there is a data transmission

SRtxi = (1- $\alpha$ ) SRtxi, if there is a timeout

iii. *Link Weight*

Link Weight (WL), is defined using the following Eq (3)

$$\text{Link Weight (WL)} = (EL * we + SRtx * wt) \quad (3)$$

where,

E – Energy level of the next hop node
we – weight assigned for EL
SRtx – Transmission success rate
wt – weight assigned for SRtx

Weights, we and wt, may be determined at run time but their sum must be equal to 1.

Link Weight then acquires a value from 0 to 100 and a higher value designates a better link. Since the link performance is not known, a random value is initially assigned to T. When subsequent packet transmissions succeed (or fail), T increases (or decreases). Initially E starts at 100 and reduces, when a node consumes its energy resources.

### c) *Multipath and Multisink Routing Technique*

Our proposed technique encompass of two phases,

- Neighbor and Representative Table Construction,
- Route Selection

The above two phases are detailed in the below two sections.

i. *Proposed Architecture*

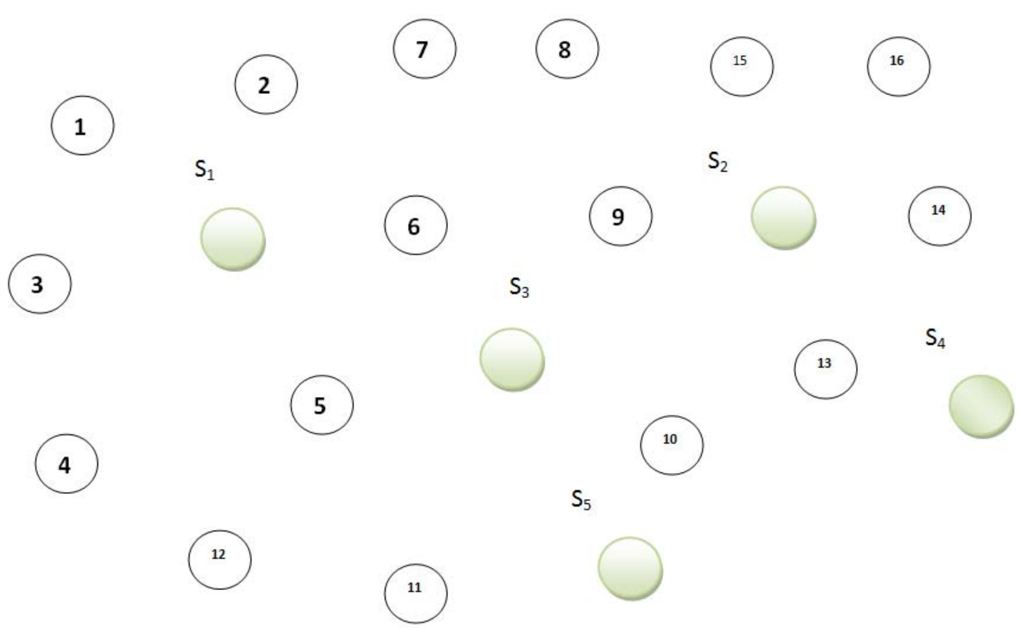


*Figure 1 :* Multiple Sink Architecture

Fig. 1 demonstrates the multiple sink architecture. It is modeled to contain multiple sink nodes (S1, S2, S3, S4, and S5). The neighbor node of each sink node is termed as representative nodes (RNi). All RNi have one hop communication with sink nodes. (Shown in fig 2).

Neighbor and Representative Table Construction

The steps involved in the construction of neighbor and representative table are as follows:

*Step 1*

When the nodes are deployed in the network, it initially broadcasts Hello packets to its neighbor nodes to obtain the neighbor and representative nodes information.

The format of the hello message is shown in table 1

*Table 1 :* Format of Hello Messages

| Node ID | Neighbor Node ID | Representative Node ID | Hop Count | Next Hop Node | Residual Energy | Transmission Success Rate |
|---|---|---|---|---|---|---|

*Step 2*

Based on the received information, each Ni constructs two tables such as Neighbor Table (NT) and Representative Table (RT). (Shown in table 2 and table 3).

*Table 2 :* Neighbor Table

| Neighbor Node ID | Residual Energy | Transmission Success Rate |
|---|---|---|

*Table 3 :* Representative Table (RT)

| Representative Node ID | Hop Count | Next Hop Node |
|---|---|---|

The neighbor Table contains neighbor node ID, residual energy of neighbor nodes and transmission success rate (Estimated in section 3.2.1 and 3.2.2).

The Representative table comprise of Representative ID, hop count and next hop. Hop count is the hop level between Ni and RNj. Next hop is the next neighbor ID from Ni to RNj.

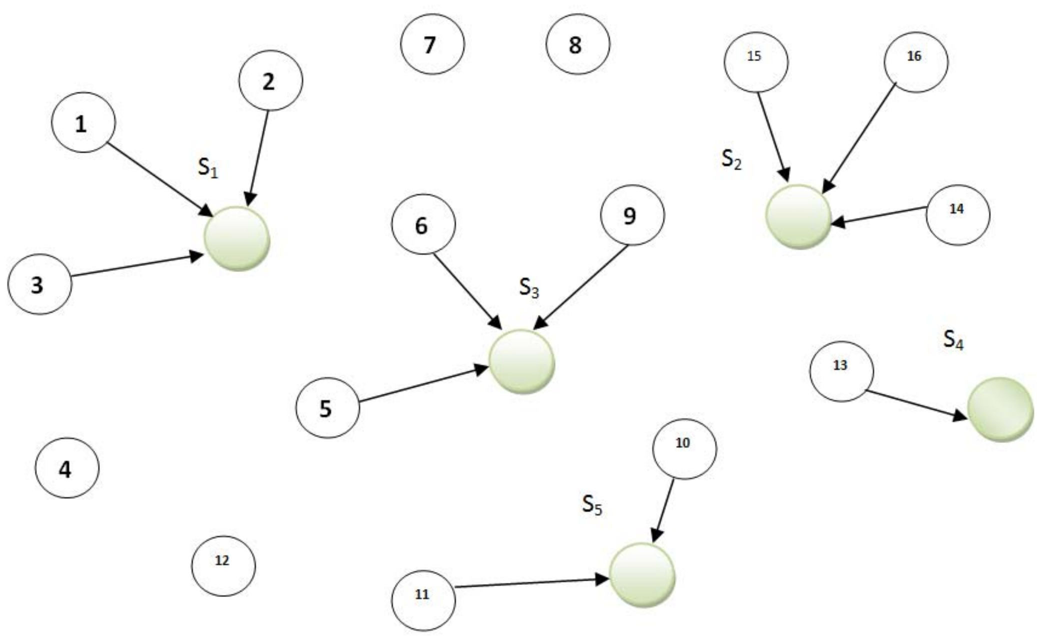


*Figure 2 :* Representation of Sink, Neighbor and representative node

From Fig 2, S1- S5 represents the sink node. [RN1, RN2 & RN3], [RN14, RN15, RN16], [RN5, RN6, RN9], [RN13] and [RN10, RN11] are representative nodes corresponding to sink S1, S2, S3, S4 and S5.

ii. *Route Discovery*

The route discovery algorithm is described using the following steps:

*Step 1*

When S wants to transmit a data packet to D, it verifies its neighbor and representative routing table for path availability.

If path exists

Then

Goto step 10

Else

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Goto Step 2
End if

*Step 2*

S broadcasts RREQ packet towards the D through the intermediate representative nodes (RNi).

$$S \xrightarrow{*RREQ} RNi \xrightarrow{*RREQ} D$$

*Step 3*

Ni upon receiving the RREQ, updates its neighbor and representative table (shown in table 2 and 3) with the nodes information.

*Step 4*

Ni then either re-broadcasts the RREQ to its neighbours or sends the route reply (RREP) if the node is D. This process is repeated till RREQ reaches D.

*Step 5*

When D receives RREQ, for every received RREQ the RREP packet is unicasted in the reverse path towards the source.

*Step 6*

Every Ni that receives RREP updates its cache for the next-hop of the RREP and then unicasts this RREP in the reverse-path using the earlier-stored previous-hop node information.

*Step 7*

Step 6 is repeated till RREP reaches S.

*Step 8*

S then computes link weight (Estimated in section 3.2.3) based on the collected information from RREP.

*Step 9*

S transfer data packets to the next hop towards the destination by considering link weight (WL) metric. i.e. the paths with best link weight is chosen for data transmission among the source and sink. The path with the next higher level of link weight in chosen as backup (alternate path).

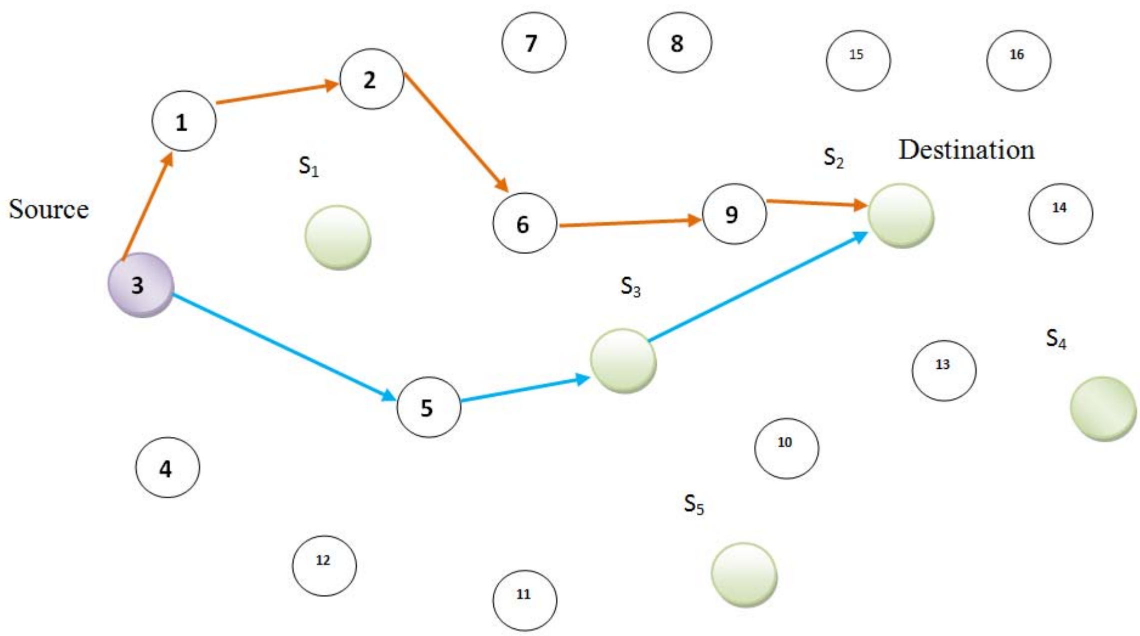


*Figure 3 :* Multipath Route Discovery

Fig. 3 demonstrates the multipath route discovery in multisink architecture. N3 represents the source and S2 represents the destination node. [RN3- RN1- RN2 -RN6 -RN9 -S2] represents the primary path. [RN3- RN1- RN2 -RN6 -RN9 -S2] represents the alternate path.

## IV. Simulation Results

*a) Simulation Parameters*

We evaluate our Reliable and Energy Saving Multipath Routing in Multisink (RESMR) through NS2 simulation. We use a bounded region of 500 x 500 sqm, in which we place nodes using a uniform distribution. We assign the power levels of the nodes such that the transmission range and the sensing range of the nodes are all 75 meters. In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. In our simulation, sensor nodes of sizes 20,40,60,80 and 100 are for 50 seconds of simulation time. The simulated traffic is Constant Bit Rate (CBR). All experimental results presented in this section are averages of five runs on different randomly chosen scenarios.

The following table summarizes the simulation parameters used:

| No. of Nodes | 20,40,60,80 and 100 |
|---|---|
| Area Size | 500 X 500 |
| Mac | 802.11 |
| Simulation Time | 50 sec |
| Traffic Source | CBR |
| Packet Size | 512 |
| Transmit Power | 0.660 w |
| Receiving Power | 0.395 w |
| Idle Power | 0.335 w |
| Initial Energy | 3.1 J |
| Routing Protocol | RESMR |

*b) Performance Metrics*

We compare the performance of our proposed RESMR protocol is compared with the previous Adaptive Energy Saving and Reliable Routing Protocol (AESRRP) [10]. We evaluate mainly the performance according to the following metrics:

Average Packet Delivery Ratio: It is the ratio of the No. of packets received successfully and the total no. of packets sent.

Average Energy Consumption: The average energy consumed by the nodes in receiving and sending the packets are measured.

Average end-to-end delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Drop: It is the total number of packets dropped during the data transmission.

*c) Sparse Scenario*

In this scenario, nodes are varied from 20 to 100.

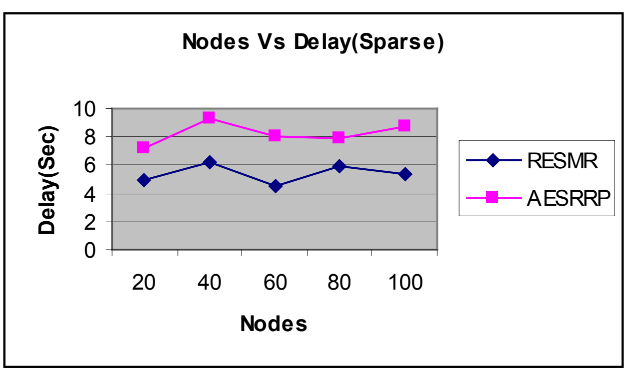


*Figure 4 :* Nodes Vs Delay

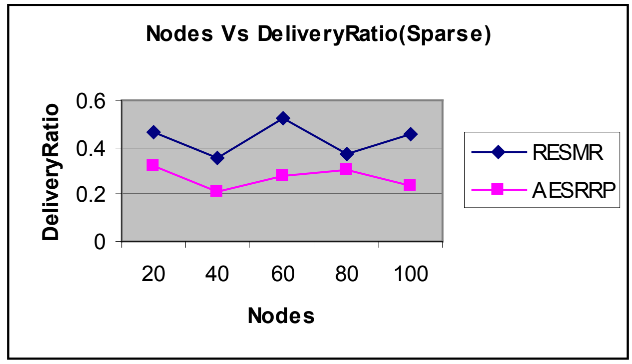


*Figure 5 :* Nodes Vs Delivery Ratio

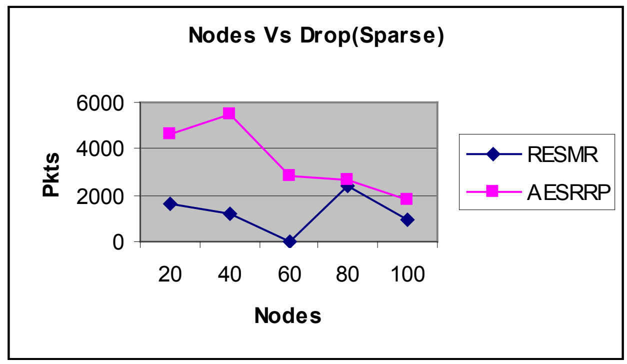


*Figure 6 :* Nodes Vs Drop

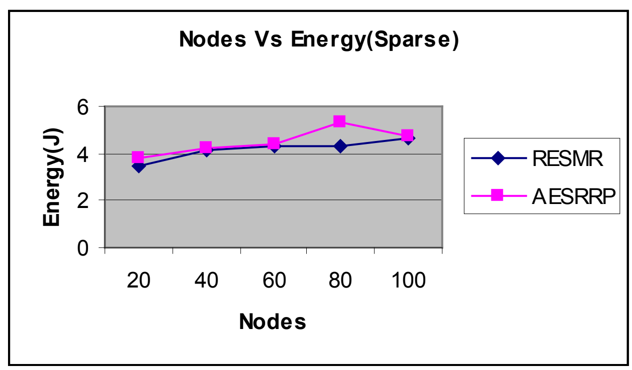


*Figure 7 :* Nodes Vs Energy

From figure 4, we can see that the delay of our proposed RESMR is less than the existing AESRRP protocol.

From figure 5, we can see that the delivery ratio of our proposed RESMR is higher than the existing AESRRP protocol.

From figure 6, we can see that the packet drop of our proposed RESMR is less than the existing AESRRP protocol.

From figure 7, we can see that the energy consumption of our proposed RESMR is less than the existing AESRRP protocol.

*d) Dense Scenario*

In this scenario, nodes are varied from 20 to 100.

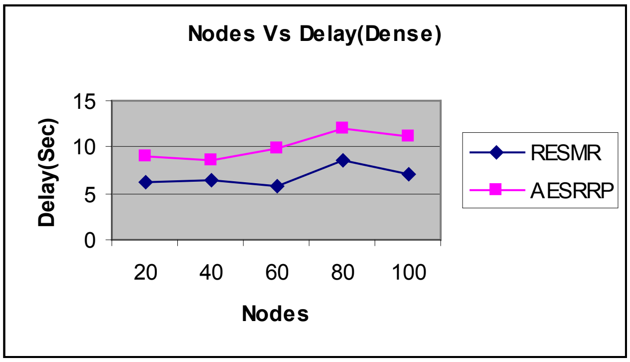


*Figure 8 :* Nodes Vs Delay

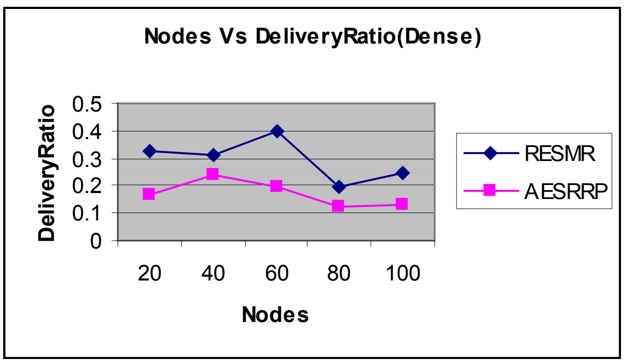


*Figure 9 :* Nodes Vs Delivery Ratio

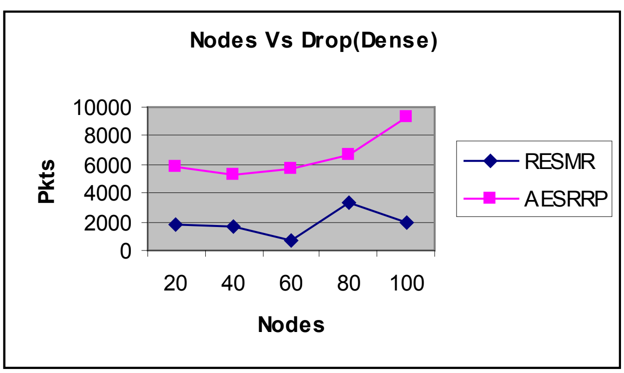


*Figure 10 :* Nodes Vs Drop

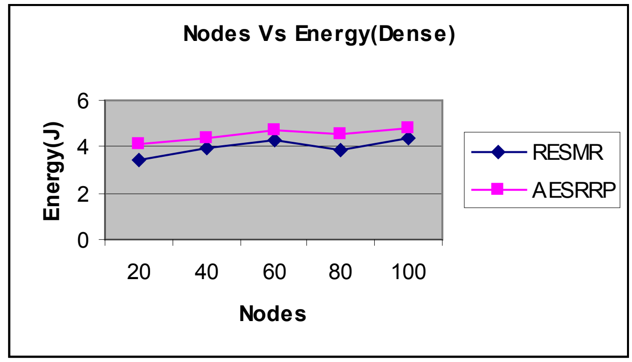


*Figure 11 :* Nodes Vs Energy

From figure 8, we can see that the delay of our proposed RESMR is less than the existing AESRRP protocol.

From figure 9, we can see that the delivery ratio of our proposed RESMR is higher than the existing AESRRP protocol.

From figure 10, we can see that the packet drop of our proposed RESMR is less than the existing AESRRP protocol.

From figure 11, we can see that the energy consumption of our proposed RESMR is less than the existing AESRRP protocol.

## V. Conclusion

In this paper, we have proposed a multipath routing in multisink wireless sensor networks. The proposed architecture contains multiple sink nodes and neighbors of sink nodes are considered to be representative nodes which are in one hop distance. Initially, each node constructs neighbor and representative node table using the parameters such as residual energy, transmission success rate, hop count and node's identity. When the node wants to transmit the data from source to destination, it establishes the multiple optimal paths for data transmission based on link weight estimated based on the parameters such as energy level and transmission success rate stored in neighbor table. By simulation results, we have shown that the proposed approach minimizes the energy consumption and link failures.

## References Références Referencias

1. I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, A survey on sensor networks, IEEE Communications Magazine 40 (8) (2002) 104–112.
2. J. Yick, B. Mukherjee, D. Ghosal, Wireless sensor network survey, Computer. Networks, 52 (12) (2008), pp. 2292–2330.
3. Culler David, Deborah Estrin, Srivastva Mani. Overview of Sensor Networks. IEEE Computer Society. August 2004.

4. G. Wener-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees, M. Walsh, Deploying a wireless sensor network on an active volcano, Data-Driven Applications in Sensor Networks (Special Issue), IEEE Internet Computing, March/April 2006.
5. G. Simon, M. Maroti, A. Ledeczi, G. Balogh, B. Kusy, A. Nadas, G. Pap, J. Sallai, K. Frampton, Sensor network-based countersniper system, in: Proceedings of the Second International Conference on Embedded Networked Sensor Systems (Sensys), Baltimore, MD, 2004.
6. J. Yick, B. Mukherjee, D. Ghosal, Analysis of a Prediction-based Mobility Adaptive Tracking Algorithm, in: Proceedings of the IEEE Second International Conference on Broadband Networks (BROADNETS), Boston, 2005.
7. T. Gao, D. Greenspan, M. Welsh, R.R. Juang, A. Alm, Vital signs monitoring and patient tracking over a wireless network, in: Proceedings of the 27th IEEE EMBS Annual International Conference, 2005.
8. K. Lorincz, D. Malan, T.R.F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, M. Welsh, S. Moulton, Sensor networks for emergency response: challenges and opportunities, Pervasive Computing for First Response (Special Issue), IEEE Pervasive Computing, October–December 2004.
9. E.M. Petriu, N.D. Georganas, D.C. Petriu, D. Makrakis, V.Z. Groza, Sensor-based information appliances, IEEE Instrumentation and Measurement Magazine (December 2000) 31–35.
10. J.M. Rabaey, M.J. Ammer, J.L. da Silva Jr., D. Patel, S. Roundy, PicoRadio supports ad hoc ultra-low power I.F. Akyildiz et al. / Computer Networks 38 (2002) 393–422 421 wireless networking, IEEE Computer Magazine (2000) 42–48.
11. G. Padmavathi, D. Shanmugapriya, M. Kalaivani, “A study on vehicle detection and tracking using wireless sensor networks”, Journal of Wireless Sensor Network, Scientific Research, 2 (2) (2010), pp. 173–185.
12. M. Castillo-Effen, D.H. Quintela, R. Jordan, W. Westhoff, W. Moreno, Wireless sensor networks for flash-flood alerting, in: Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits, and Systems, Dominican Republic, 2004.
13. Wireless Sensor Networks in Agriculture: For Potato Farming, Kshitij Shinghal, Dr. Arti Noor, Dr. Neelam Srivastava, Dr. Raghuvir Singh International Journal of Engineering Science and Technology 2010; 2(8):3955-3963.
14. K. Akkaya, M. Younis, A survey of routing protocols in wireless sensor networks, Ad Hoc Network (Elsevier) 3 (3) (2005) 325–349.
15. Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., Anderson, J.: Wireless sensor networks for habitat monitoring. In: Proc. of the 1st ACM Int. Workshop on Wireless sensornetworks and applications. (2002) 88–97.
16. Y Chen, E Chan and Song Han, ”Energy efficient multipath routing in large scale sensor networks with multiple sink nodes”, The 6th International Workshop on Advanced Parallel Processing Techniques, pp.390399, Hong Kong, 2005.
17. Akyildiz, I.F., Kasimoglu, and I.H.: Wireless sensor and actor networks: Research challenges. Ad Hoc Networks Journal 2(4) (2004) 351–367.
18. K. Sha, J. Gehlot and R. Greve, Multipath Routing Techniques in Wireless Sensor Networks: A Survey, Wireless Pers Commun, Springer, June 2012.
19. Di Tian and Nicolas D. Georganas, “Energy Efficient Routing with Guaranteed Delivery in Wireless Sensor Networks”, Proceedings of IEEE Wireless Communications and Networking Conference, (WCNC), pp-1923-1929, 2003.
20. Marjan Radi, Behnam Dezfouli, Kamalrulnizam Abu Bakar and Malrey Lee, “Multipath Routing in Wireless Sensor Networks: Survey and Research Challenges”, Sensors, pp-650-685, 2012.
21. Hwee-Pink Tan, Adriana F. Gabory, Winston K. G. Seahz and Pius W. Q. Lee, “Performance Analysis of Data Delivery Schemes for a Multi-sink Wireless Sensor Network”, IEEE 22nd International Conference on Advanced Information Networking and Applications, (AINA 2008), 2008.
22. Min Meng, Hui Xu, Xiaoling Wu, Brian J. d'Auriol1, Byeong-Soo Jeong, Sungyoung Lee, “PBR: Priority Based Routing in Multi-sink Sensor Networks”, in Proceedings of International Conference of Wireless networks, pp.380-386, 2007.
23. Winston K.G. Seah and Hwee Pink Tan, “Multipath Virtual Sink Architecture for Wireless Sensor Networks in Harsh Environments”, Proceedings of the ACM first international conference on Integrated internet ad hoc and sensor networks, (InterSense '06), 2006.
24. Hongseok Yoo, Moonjoo Shim and Dongkyun Kim, “A scalable multi-sink gradient-based routing protocol for traffic load balancing”, EURASIP Journal on Wireless Communications and Networking, 2011.
25. Emanuele Cipollone, Francesca Cuomo, Sara Della Luna, Ugo Monaco and Francesco Vacirca, “Topology Characterization and Performance Analysis of IEEE 802.15.4 Multi-Sink Wireless Sensor Networks”, in IFIP, Advances in Ad Hoc.
26. Raminder Singh, Harbhajan Singh, R.S. Kaler, "An Adaptive Energy Saving and Reliable Routing Protocol for Limited Power Sensor Networks," IEEE International Conference on Advances in Computer Engineering, pp.79-85, 2010.
27. Luca Mottola and Gian Pietro Picco, “MUSTER: Adaptive Energy-Aware Multi-Sink Routing in

Wireless Sensor Networks", IEEE Transactions on Mobile Computing, pp- 1694 – 1709, 2011.
28. Pietro Ciciriello, Luca Mottola and Gian Pietro Picco, "Efficient Routing from Multiple Sources to Multiple Sinks in Wireless Sensor Networks", Proceedings of the ACM 4th European conference on Wireless sensor networks(EWSN'07), 2007.
29. Haiyang Liu, Zhi-Li Zhang, Jaideep Srivastava, and Victor Firoiu, "PWave: A Multi-source Multi-sink Anycast Routing Framework for Wireless Sensor Networks", Proceedings of the 6th international IFIP-TC6 conference on Ad Hoc and sensor networks, (NETWORKING'07), 2007.
30. Chunping Wang and Wei Wu, "A Load Balance Routing Algorithm for Multi-sink Wireless Sensor Networks", IEEE International Conference on Communication Software and Networks, 2009.
31. Preetha Thulasiraman, Srinivasan Ramasubramanian, and Marwan Krunz, "Disjoint Multipath Routing to Two Distinct Drains in a Multi-Drain Sensor Network", 26th IEEE International Conference on Computer Communications, (INFOCOM'07), 2007.
32. K.Sheela Sobana Rani and N. Devarajan, "Fuzzy Based Optimization for Power Management in Wireless Sensor Networks", International Journal of Computer Applications, Volume 48– No.4, June 2012.
33. Network Simulator: http:///www.isi.edu/nsnam/ns