Indian Journal of Science and Technology, Vol 10(17), DOI: 10.17485/ijst/2017/v10i17/106581, May 2017
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Multipath Routing Protocols in Wireless Sensor Networks: A Retrospective Review

N. Vijayarani[1]* and A. Senthilkumar[2]

[1]Department of Computer Science, Bharathiar University, Coimbatore – 641046, Tamil Nadu, India; n.vijayarani.mca@gmail.com
[2]Department of Computer Science, Arignar Anna Government Arts College, Namakkal - 637002, Tamil Nadu, India; senthilkumarmca76@gmail.com

Abstract

Objectives: To review the basic principles of Multi-path Routing Protocols (MRPs) design and its performance metrics. To discuss the assortment of MRPs overview for Wireless Sensor Networks (WSNs) based on its arrangement and delivery. **Methods/Statistical Analysis:** The enhanced reliability, load balance and security promote the multi-path routing as an appropriate tool in the domain of Wireless Sensor Networks (WSNs). In order to obtain simultaneous data transfer with reduced delay period, critical review is made based on the performance metrics, taxonomy of MRPs, and qualitative comparison. **Findings:** From the discussions, it can be concluded that most of the protocols achieved better load balance with improved performance. Coding based MRPs can perform with better reliability when compared to other protocols. **Application/Improvements:** The survey of earlier reports led to the decisions that the energy-efficient, reduced transmission delay with multiple pairs is the details to be studied in the domain of MRPs.

Keywords: Energy Efficiency, Path Discovery, Routing Protocols, Wireless Sensor Networks

1. Introduction

WSN consists of spatially distributed and storage that can used as inexpensive and independent device with computational ability in order to monitor physical and environmental conditions. These sensors sense the changes in the testing sections and transfer the data to sink node (or) base station[1,2]. The current progresses in WSNs have been successfully implemented in crucial applications such as remote sensing, traffic monitoring, and weather monitoring and healthcare[3-6].

Routing plays a vital role in WSNs due to constrained available resources in terms of computational ability, energy and storage space[7,8]. The routing techniques are generally classified as single path routing and multi-path routing. İn single path routing, the path between the source and target can be documented in a specific time. It also includes the appreciable characteristics such as, trouble-free and scalable. However, the single path routing is not efficient due to depletion of power, shorter life-time and limited storage space[9].

In multi-path routing, multiple paths are selected to deliver the data between the source and destination. İn wireless communication, neighbour nodes shared the bandwidth among them and the nodes interfere with geographically close nodes resulting in reduces the throughput of the network. In order to ensure the efficiency in wireless communication, muti-path routing is a promising alternative technique to overcome the difficulties such as reliability, load balance, and bandwidth improvement[10].

The use of muti-path routing in WSNs is the active field of research for the past two decades. Many researchers critically reviewed the importance of different protocols. However, there is a need of close approach with the protocols to analyze the capacity and confront to design the

*Author for correspondence

MRPs. The present study addresses the basic principle to design the WSNs based MRPs, challenges in implementation and there evaluation.

2. Basic Principle to Design Multi-Path Routing Protocol

For any protocols, the embedded components should have the capacity to create multiple paths and distribute the network traffic across the discovered paths. In MRP techniques, protocol ability to construct a sufficient number of high-quality paths directly affects the performance gain. The components involved in multi-path construction will distribute network traffic over the discovered path and maintained path. The present chapter discusses the important components for multi-path routing.

2.1 Path Discovery

Path discovery is a central constituent to design MRPs. Multi-hop data forwarding is a conventional method adapted to distribute the data in WSNs[11]. In order to frame regular paths between the source and sink, couple of transitional nodes are to be exposed. The multi-path routing paths are generally classified as; non-disjoint paths and disjoint paths[12].

The non-disjoint paths (or) joint multi-paths, having common links and nodes that can allow any loop-free paths. In disjoint multi-path, based on degree of independence of each path, disjoint paths are discovered. The disjoint path makes the alternative path to act independent without affecting the primary path[13]. These paths can be grouped as; link-disjoint multi-path, node-disjoint multi-path, totally disjoint multi-path, braided multi-path and zone-disjoint multi-path.

2.2 Path Selection and Traffic Distribution

Path selection and traffic distribution is another critical constituent in MRPs. In multi-path routing design, explicit number of paths should be identical in the performance criteria for the particular application. In order to acquire superior performance in MRP, approximate amount of path selection should be essential. It is necessary for routing protocol to identify the network sharing. Through the individual path, resource maximization is identified, where as the injected traffic is measured in terms of path capacity on all paths[14]. The path selection may be one path at a time or simultaneous use of K-paths or all paths at the same time.

Traffic distribution is also an important constituent in MRPs, which can directly, affects the resulting performance. The multi-path routing algorithms should divide the passage into a known set of paths through recognition in context of flow control[15]. It will depend on number of paths and allocation of granularity[16,17].

2.3 Path Maintenance

WSNs are liable to constrained nodes, nodes or link failures. The path re-creation should have mechanism to limit performance degradation. During the route failure, the initiation of route discovery process may lead to high overheads[17]. The path maintenance tool involved the following aspects; activation of failed paths, activation of all failed paths and activation of specific amount of paths, which have failed to respond. In general, activation of specific amount of paths, which have failed to respond, is most suitable in WSNs multi-path routing protocol[12].

3. Performance Metrics

The following chapter examines about the performance metrics of MRPs to evaluate the rewards and overheads.

3.1 Energy Efficiency

To evaluate the energy efficiency of MRPs, network lifetime combined energy consumption in sensing, computation, communication and network coverage are considered[18,19]. The total number of messages transmitted in multi-path protocol is also to be a good metric to evaluate the energy, since it consumes most significant energy. The lifetime of sensor networks and network congestion are depends on load balance. Hence, load balance is also to be considered.

3.2 Route setup Time

As already discussed, path discovery is a challenging task in MRPs. To assess the overhead of MRPs, the total duration of source node to discover the paths (from source to destination) is to be measured. In order to obtain enhanced performance, lesser route setup time protocols to be designed.

3.3 Reliability

In general, data reliability in measured based on number of messages received at the destination node and total number of messages initiated from the source node. D1ata reliability refers the percentage of successfully

received data packets in the destination node. The reliability of protocols strongly depends on number of paths discovered. Hence, more discovered paths are required to obtain better data reliability.

3.4 Average Delay Period

Average delay period is the time taken by the data packet to travel from source and destination. Usually, MRPs requires a longer path than single path routing, since high load balance and reliability are of concerned. Heavy computation at intermediate nodes and network traffic lead to delay in packet arrival at destination node. In order to evaluate average delay, routing path length, another metric is also employed. The routing path length also reflects the energy efficiency of the routing protocols.

4. Taxonomy of MRPS

To achieve more data reliability, high security and balanced load, various multi-path protocols were developed and implemented in WSNs by many researchers. Based on the existing protocols, multi-path protocols are commonly classified based on their infrastructure and coding. Figure 1 shows the common organization of MRPs proposed for WSNs. Infrastructure based protocols allowed to maintain multi-paths from source to destination, whereas non-infrastructure based protocols do not allowed to establish multi-paths. Another classification coding based protocols is classified based on coding and data fragmentation techniques. The following sections details the design principle of protocols under each category.

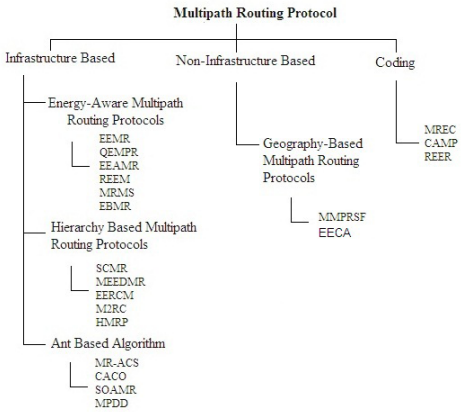

Figure 1 Organization of multi-path routing protocol.

4.1 Infrastructure based Multi-Path Routing Protocol

In infrastructure-based protocols, any explicit topology structure can implement to frame the multi-paths. The communications should provide reliable and rapid data transmission with their neighbour nodes. Besides, it leads to drop in failure recovery time. The infrastructure based multi-path protocols are further classified as; energy-aware MRPs, hierarchy-based routing protocols and ant-based algorithm and are detailed in the following sections.

4.1.1 Energy-Aware MRPs

These protocols are heuristic protocols, which can find out the adjacent hop based on energy of neighbouring nodes. Energy-aware techniques were implemented to amplify the existence of the networks, since sensors have limited amount of available energy. In data forwarding, energy-aware techniques consume low energy to choose sensors. Besides, these protocols reduce much amount of the communication overhead. Hence, these techniques assumed to be a good heuristic protocol. The protocols in this category are presented in the following discussions.

4.1.1.1 Energy-Efficient Multiple Routing (EEMR) Protocol

In order to recognize node-disjoint multi-paths among the source and sink node, EEMR protocol is developed[20]. In EEMR, by considering link cost function, multi-paths are created that includes energy level as well as hope distance. Load balancing algorithm with EEMR protocol leads to distribute uniform load throughout the network.

4.1.1.2 QoS and Energy-Aware MRP (QEMPR)

QoS and energy-aware MRP are implemented by using link quantity as a performance metrics[21]. In QEMPR, every nodes having a unique ID with link quality information that can able to calculate the packet receiving and sending probability. The paths are identified using message broadcasting and the nodes stored the information about adjacent nodes. After that, the packets are transmitted with respect to number of hops and packet sequence number. This technique leads to uniform distribution of network traffic and increase the network lifetime.

4.1.1.3 *Energy Efficient Adaptive Multi-path Routing (EEAMR) protocol*

EEAMR protocol is proposed to distribute the traffic with respect to node's residual energy and signal strength. In EEAMR protocol, higher load is allocated to under-utilized path and lower load is allocated to over-utilized path in order to consistent resource utilization. Besides, nodes, which are all in, idle condition forced to sleep mode to save more energy[22].

4.1.1.4 *Reliable and Energy Efficient Multi-path (REEM) Routing Protocol*

In REEM protocol, multi-paths are created from source to sink by considering node energy level and reliability. Base station is involved to construct the multi-paths and the receiver nodes stored the adjacent nodes information in a table. Besides, the base station evaluates the path reliability based on the adjacent nodes information[23].

4.1.1.5 *Multi-path Routing with Multiple Sink (MRMS) nodes Protocol*

MRMS protocol is proposed to construct energy efficient in large scale WSNs. In MRMS nodes protocol, multiple sink nodes are deployed and path cost metric is used to identify multi-paths. Based on distance between neighbour nodes, available energy and hop count, path cost metrics are represented[24].

4.1.1.6 *Energy-Balancing Multi-Path Routing (EBMR) Protocol*

EBMR protocol is developed with respect to client-server architecture and base station processing data, in order to overcome the need of node's sensing information collection[25]. Multi-paths are constructed with aid of message broadcasting from base station, where as each node having adjacent node's information in table. Based on the information requirements, data enquiry message is broadcasted and replied. From the replied information, base station identified the shortest path.

The above-developed protocols are succeeded in energy efficient. However, communication overhead, network traffic and malicious attacks are identified as major drawbacks[26].

4.1.2 *Hierarchy based MRPs*

Hierarchy based protocols are developed to discover efficient multi-path in order to build the infrastructure (or) hierarchical relationship. These protocols are more suitable for large scale WSNs. It also increase the network lifetime and reduce the communication overhead. The hierarchy is developed based on the receiving messages sequence. In hierarchy-based protocols, adjacent hop is selected based on hierarchal relation, whereas in energy aware- based protocols, adjacent hop is selected based on group of neighbouring nodes energy level. Hierarchy based protocols are detailed as follows.

4.1.2.1 *Secure Cluster based MRPs (SCMR)*

In SCMR protocols, tree based algorithm was developed to solve complex computational problems. In order to achieve better QoS in multimedia application, the network nodes processed the data frequently and lead to higher energy depletion. To avoid these phenomena, hierarchical structure of multi-paths is used based on the cluster. In SCMR, each cluster node is connected with the sink either directly or through other cluster head nodes[27]. These cluster nodes are more influential than remaining nodes in terms of available energy and resources.

4.1.2.2 *Minimized End-to-End Delay MRP (MEEDMR)*

MEEDMR is proposed for mission critical WSNs application using multi-paths that are based on the benefits of the tree structure. Tree based search algorithm is initiated to discover multi-paths and alternative paths. The data packets are transferred through multi-paths in order to obtain reliable transmission. The route maintenance is initiated at the time of low end-to-end reliability[28].

4.1.2.3 *Energy Efficient Reliable Co-operative MRPs (EERCM)*

EERCM routing protocols are developed to obtain data reliability based on a set of relay nodes. By using hierarchy position, the relay nodes are identified. Besides, the EERCM protocol avoided the bottleneck nodes to achieve efficient energy[29]. The bottleneck nodes can able to affect the network throughput and network lifetime.

4.1.2.4 *Multiplicative-Increase/Additive-Decrease MRPs (M2RC)*

M2RC protocol is acknowledged as the next hop, based on the error condition of downstream adjoining nodes. Every node in the network is assigned with cost value that

can describe the required power to transfer the packet from source to destination. Based on the requirements, base node transmits the message with cost value and received the packet with lower cost value[30].

4.1.2.5. Hierarchy based MRPs (HMRP)

HMRP is designed to focuses on energy limitation, scalability, simplicity and better network lifetime in WSNs. Multi-paths are developed based on sending messages with adjacent nodes. The receiver nodes further forwarded the message to their adjacent nodes, and note them as a child node. This will continue up to each node finds its own child node. Each source node makes to wait for acknowledgement from destination during the reliable data transmission[31].

The above-discussed protocols are based on hierarchal techniques. Hierarchy based protocols provides a reliable mechanism to construct and maintain multiple paths with resource constrained environment. However, Load balance and optimal path identification are identified as a major concern in WSNs.

4.1.3 Ant based Algorithm

Ant based algorithm is projected to construct multi-paths, in which the algorithm is followed on population metaheuristic approach. By observing the activities of ants to locate the undeviating path among the food source and nest, ant based algorithm is developed. Ant based algorithms are detailed as follows.

4.1.3.1 MRP using Ant Colony System (MR-ACS)

In MR-ACS approach, ants search the path parallel in order to find the paths quickly. The forwarded node can built the paths based on metaheuristic approach to each intermediate node. If another node is already approached, the intermediate node will overlook the forward node. Or else, the intermediate node may inspect the nearness of the node, modernize the message accordingly and find the optimum path[32].

4.1.3.2 Clustering and Ant Colony Optimization (CACO) Algorithm

CACO protocol is developed based on dynamic clustering and ant colony optimization algorithm[33]. In the three phases of algorithm, cluster head is selected based on the residual energy and signal strength in the first phase. Whereas, multi-path between cluster head and sink node is selected in the second phase based on ant based approach and dynamic route to transmit the data is achieved in the third phase.

4.1.3.3 Self-Optimized Algorithm using Multi-path Routing (SOAMR)

In SOAMR approach, the shortest path is determined based on ant-based algorithm and the routing decision is based on forwarding metrics[34]. This algorithm is most suitable for single path routing as well as multi-path routing to achieve best data throughput.

4.1.3.4 Multiple Path Directed Diffusion (MPDD)

MPDD protocol is an extended version of direct diffusion protocol, in which multi-path routing is incorporated with direct diffusion. MPDD protocols leads to efficient energy uses and uniform load distribution[35].

The above ant-based algorithm has favourable characteristics such as, simple construction, uniform load distribution, efficient energy usage and dynamic environment approach. However, slow response and high overhead are identified as undesirable characteristics.

4.2 Non-Infrastructure based MRPs

Non-infrastructure protocols do not create infrastructure to transmit the packets. The non-infrastructure based protocols vary from infrastructure protocols in terms of path discovery and node's decision-making. These non-infrastructure MRPs are having the appreciation characteristics such as; absence of path maintenance, balanced load and better decision-making. On the other hand, forwarding the data packet in the direction of receiver is the major concern in non-infrastructure protocols, which will leads to significant delay in packet delivery and more energy consumption. The present section discusses the geography-based MRP, which is one of the special types of non-infrastructure protocol.

4.2.1 Geography-based MRPs

Geography-based protocols are developed by considering the local information of the nodes. Based on the location of source, adjacent and neighbour nodes, routing decision is framed. The geography-based multipath routing protocols are having the following merits such as; absence of huge neighbouring tables, path maintenance,

and less number of transmissions. The protocols under this category are discussed as follows.

4.2.1.1 Meshed Multi-Path Routing with Selective Forwarding (MMPRSF) Protocol

MMPRSF protocol is developed based on meshed multi-path routing. This meshed routes leads to multiple choices to transfer the data. The nodes are static and location information is transmitted across the network[36]. Based on the discovered query messages, the nodes replied to the sender with confirmation messages. This approach is mostly suitable to accomplish better load balancing.

4.2.1.2 Energy Efficient Collision Aware (EECA) MRP

EECA protocol proposed to design collision free multi-paths. To convey the packet towards the base station, route discovery message is sent out to the neighbouring nodes. The nodes transmit the route detection messages with aid of location information. To transmit the data packet, base node is identified the neighbouring nodes and chooses two groups of node by considering the distance between the each node[37].

The above protocols lead an efficient multi-path routing approach that is incorporating geography information. On the other hand, local maximum phenomena and malicious attacks are identified as critical issues in WSNs[38].

4.3 Coding based MRPs

Coding practices are applied to construct MRPs in data transmission. Path constructions and its maintenance are major concern in infrastructure-based protocols, whereas non-secure data transmission and lower percentage of successful packet delivery are concern in non-infrastructure based protocols. Coding techniques are developed to overcome the common issue such as, unnecessary redundancy and security. The coding techniques can avoid malicious attack and much energy consumption. In coding techniques, data packets split into fragments at the source node and transmitted to different discovered paths. The coding based MRPs are discussed as follows.

4.3.1 Multi-path routing using Erasure Coding (MREC)

MREC protocol applies anon-demand routing algorithm, in which the new path is created from base station to end at the time of need. Thus, it reduces the energy consumption. Multi-paths are created using message broadcasting and make reply based on the request message. The data splitting technique, i.e. erasure coding is used to avoid redundant transmission[39]. In MREC technique, the quantity of data transmission is low due to transfer of data in terms of fragments. It may leads to more energy conservation and better network lifetime.

4.3.2 Coding Aware Multi-path Routing (CAMP) Protocol

CAMP is proposed to achieve data reliability with secure. It focuses the increases in network throughput in the way of reliability and better coding, which is working on two phases. Construction of multi-path with aid of message broadcasting is the first phase, whereas transmission of packet through multi-path with use of network coding is the second phase[40]. CAMP protocol having a flexibility to decide the path based on reliability and better transmission.

4.3.3 Robust and Energy-Efficient Multi-path Routing (REER) Protocol

REER is another multi-path routing protocol, which are followed two different approaches for traffic allocation. Data transfer using single optimal path is a first phase, whereas use of multi-paths with XOR based error correction is a second phase. In REER protocol, each node having a neighbouring table that contains basic information. The best hope is identified based on the link cost function[40].

5. Qualitative Comparison of the Performance of MRPS

The qualitative comparisons of MRPs are represented in Table 1. It is observed that coding based MRPs show enhanced performance compared with those other MRPs. This may due to better reliability of coding based protocols due to number of paths. It is also noted that many protocols will not achieve the shortest path. However, most of the protocols lead to better load balancing and improved performance. Energy efficient and minimize the data packet loss due to simultaneous data transmission is proposed to be a further development in multi-path routing protocol techniques.

Table 1 Comparison of the performance of MRPs.

	lıfe tıme	Load balancing	Packet delivery rate	No. of paths	Route setup time	Amount of traffic	Average path length	Average delay
Energy-Aware MRPs								
EEMR	✓	✓				✓	✓	✓
QEMPR		✓				✓		✓
EEAMR	✓						✓	✓
REEM		✓						✓
MRMS	✓	✓				✓	✓	✓
EBMR							✓	✓
Hierarchy based MRPs								
SCMR							✓	✓
MEEDMR					✓	✓	✓	✓
EERCM		✓			✓			
M2RC	✓	✓			✓	✓	✓	✓
HMRP					✓		✓	✓
Ant Based Algorithm								
MR-ACS					✓			
CACO		✓			✓	✓		
SOAMR					✓	✓	✓	✓
MPDD		✓	✓	✓				
Geography-Based Multipath Routing Protocols								
MMPRSF	✓			✓		✓		
EECA		✓			✓	✓	✓	✓
Coding Based MRPs								
MREC		✓	✓	✓		✓	✓	✓
CAMP	✓	✓		✓	✓		✓	✓
REER	✓	✓		✓		✓	✓	✓

6. Conclusion

The basic principle to design the MRPs and performance metrics are critically reviewed and various types of MRPs presented. From the discussions, it may be concluded that most of the protocols achieved better load balance with enhanced performance. Coding based MRPs can perform with better reliability. Based on the above conclusions, energy efficient and minimize the data packet losses in transmission are suggested as future invention in the domain of MRPs in WSNs.

7. References

1. Lou W. An efficient n-to-1 multipath routing protocol in wireless sensor networks. In Proceedings of Mobile Adhoc and Sensor Systems Conference. 2005.
2. Vidhyapriya R, Vanathi PT. Energy efficient adaptive multipath routing for wireless sensor networks. International Journal of Computer Science (IAENG). 2007; 34(1):1–9.
3. Yu H, Guo M. An efficient freeway traffic information monitoring systems based on wireless sensor networks and floating vehicles. In Proceedings of the International Conference on Pervasive Computing, Signal Processing and Applications. 2010. Crossref

4. Xu N. A wireless sensor network for structural monitoring. In Proceedings of SENSYS. 2004.
5. Baker CR, Armijo. Wireless sensor networks for home health care. In Proceedings of the 21st International Conference on Advanced Information Networking and Applications Workshops. 2007; 02. p. 832–37. Crossref
6. Bokareva T, Hu W, Kanhere S, Ristic B, Bessell T, Rutten M, Jha S. Wireless sensor networks for battlefield surveillance. In Proceedings of the Land Warfare Conference. 2006.
7. AI-Karaki JN, Kamal AE. Routing techniques in wireless sensor networks: A survey. IEEE Wireless Communications. 2004; 11(6):6–28. Crossref
8. Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. Journal ofAdHoc Networks. 2004; 3:325–49. Crossref
9. Sha K, Gehlot J, Greve R. Multipath Routing Techniques in Wireless Sensor Networks: Survey Procedia Computer Science. 2016; 610–15.
10. Anasane AA, Satao RA. A Survey on various Multipath Routing protocols in Wireless Sensor Networks. Procedia Computer Science. 2016; 79:610–15. Crossref
11. Saleem I, Ullah M, Farooq B. Sensor: An energy-efficient and scalable routing protocol for wireless sensor networks. Information Sciences. 2012; 38–56. Crossref
12. Tarique MT, Adibi KE, Erfani S. Survey of Multipath Routing Protocols for Mobile Ad Hoc Networks. Journal of Network Computers. 2009; 1125–43.
13. Radi M. Multipath routing in wireless sensor networks: Survey and research challenges. Sensors. 2012; 12(1):650–85. Crossref PMid:22368490 PMCid:PMC3279234
14. Kumar Singh S, Singh MP, Singh DK. Routing Protocols in Wireless Sensor Networks–A Survey. International Journal of Computer Science and Engineering Survey (IJCSES). 2010.
15. Haider R, Javed MY, Khattak NS. Energy aware greedy routing in sensor networks. Journal of Future Generation Communication and Networking. 2007.
16. Banner R, Orda A. Multipath Routing Algorithms for Congestion Minimization. IEEE/ACM transactions on networking. 2007. Crossref
17. Tsai J, Moors A. A Review of Multipath Routing Protocols. From Wireless Ad Hoc to Mesh Networks.
18. Intanagonwiwat C, Govindan R, Estrin D. Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks, Proceedings of the 6th Annual International Conference on Mobile Computing and Networking (MobiCom '00), Boston, MA. 2000. p. 56–67. Crossref
19. Sha K, Shi W. Modeling the lifetime of wireless sensor networks. Sensor Letters. 2005; 3(2):126– 35. Crossref
20. Sha K, Shi W. Revisiting the lifetime of wireless sensor networks. In Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems. 2004. p. 299–300. Crossref
21. Lu YM, Wong VWS. An energy-efficient multipath routing protocol for wireless sensor networks. International Journal of Communication Systems. 2007; 20:747–66. Crossref
22. Heikalabad SR, Rasouli H, Nematy F, Rahmani N. Qempar: Qos and energy aware multi-path routing algorithm for real-time applications in wireless sensor networks. CoRR. 2011; abs/1104–1031.
23. Wang XH, Che CM, Li L. Reliable multi-path routing protocol in wireless sensor networks. In Proceedings of the 2010 International Conference on Parallel and Distributed Computing, Applications and Technologies. 2010. p. 289–94.
24. Chen Y, Chan E, Han S. Energy efficient multipath routing in large scale sensor networks with multiple sink nodes. Advanced Parallel Processing Technologies. 2005; 3756:390–99. Crossref
25. Yunfeng C, Nasser N. Energy-balancing multipath routing protocol for wireless sensor networks. In Proceedings of the 3rd International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks. 2006.
26. Karlof C, Wagner D. Secure routing in wireless sensor networks: Attacks and counter measures. Proceedings of First IEEE International Workshop on Sensor Network Protocols and Applications. 2003. Crossref
27. Almalkawi IT, Zapata MG, Al-Karaki JN. A secure cluster-based multipath routing protocol for wmsns. Sensors. 2011; 11(4):4401–24. Crossref PMid:22163854 PMCid:PMC3231315
28. Pratheema S, Srinivasagan KG, Naskath J. Minimizing end-to-end delay using multipath routing in wireless sensor networks. International Journal of Computer Applications. 2011; 21(5):20–6. Crossref
29. Treplan G, Tran-Thanh L, Levendovszky J. Energy efficient reliable cooperative multipath routing in wireless sensor networks. World Academy of Science, Engineering and Technology. 2010.
30. Xing Y, Nie N, Comaniciu C. Avoiding throughput bottlenecks for energy efficient joint power control and routing in ad hoc wireless networks. In Proceedings of the Conference on Information Sciences and Systems. 2004 Mar.
31. Wang YH, Mao HJ, Tsai, CH, Chuang CC. Hmrp: Hierarchy-based multipath routing protocol for wireless sensor networks. In Proceedings of EUC Workshops. 2005; 452–59. Crossref
32. Xiu LR, Hong-Wei L, Yu W. Multipath routing based on ant colony system in wireless sensor networks. In Proceedings of International Conference on Computer Science and Software Engineering. 2008. p. 202–05.

33. Yang J, Xu M, Zhao W, Xu B. A multipath routing protocol based on clustering and ant colony optimization for wireless sensor networks. Sensors. 2010; 10(5):4521–40. Crossref PMid:22399890 PMCid:PMC3292129
34. Saleem K, Fisal N, Hafizah S. A self-optimized multipath routing protocol for wireless sensor networks. International Journal of Recent Trends in Engineering (IJRTE). 2009; 2(1):1–5.
35. Eghbali AN, Dehghan M. Load-balancing using multipath directed diffusion in wireless sensor networks. In Proceedings of the 3rd International Conference on Mobile Ad-hoc and Sensor Networks. 2007. p. 44–55. Crossref
36. De S, Qiao C, Wu H. Meshed multipath routing with selective forwarding: An efficient strategy in sensor networks. Computer Networks.2003, 43, pp. 481–97. Crossref
37. Wang Z, Bulut E, Szymanski BK. Energy efficient collision aware multipath routing for wireless sensor networks. In Proceedings of the 2009 IEEE International Conference on Communications. 2009. Crossref
38. Moraru L, Leone P, Nikoletseas S, Rolim J. Geographic routing with early obstacles detection and avoidance in dense wireless sensor networks. In Proceedings of the 7th International Conference on Ad-hoc, Mobile and Wireless Networks. 2008. p. 148–61. Crossref
39. Wu J, Dulman S, Havinga P, Nieberg T. Multipath routing with erasure coding for wireless sensor networks. In Proceedings SAFE and ProRISC. 2004; 181–88.
40. Han S, Zhong Z, Li H. Coding-aware multi-path routing in multi-hop wireless networks. Proceedings of IPCCC'08. 2008. Crossref