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A Survey on Routing Techniques in ZigBee Wireless Networks in Contrast with Other Wireless Networks

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Abstract

Objectives: Nowadays wireless sensor networks are widely employed to improve business process models of industries, web service applications, defence sector, Internet of things, space exploration, etc. Mobile ad hoc networks and the sensor networks are the two major categories of wireless ad hoc network. In both types, there is no fixed topology and centralized management system. So there is in need of different conditions to design protocols for routing wireless ad hoc networks. **Method:** ZigBee is one of the renewed standard of wireless personal area network aimed to cost-effective, reliable, low-power consumption as well as products and applications are scalable. Routing among the nodes is one among the most important function in data communication networks. The standard called ZigBee will support a combination of tree routing and on-demand vector routing. **Findings:** The present study involves various routing techniques in ZigBee wireless networks in contrast with other wireless networks. Various tools were employed to compare and assess the routing protocols. The results of the study reveals shortcut tree routing have advantages of better throughput, best packet delivery ratio and a lower end to end delay. **Application:** Shortcut tree routing gives best routing path viable for the packets and also decreases tree link associated traffic load in a greater extent. Also provides recommendable routing performance to AODV reactive routing protocol.

Keywords: Mobile Ad Hoc Network, On-Demand Routing, Wireless Sensor Network, Tree Routing, ZigBee

1. Introduction

A wireless ad hoc network (WANET) is ad hoc since it is not depends on infrastructure which was preexisting one and a decentralized type of wireless network. On behalf of the connectivity of the network, the details of nodes which forward the data is made can be determined dynamically, since each node participates in routing by forwarding data for other nodes. Ad hoc networks can use flooding for forwarding data in addition to the classic routing. Self-configuring dynamic networks in which nodes are free to move can be referred to as Wireless mobile ad hoc networks and Wireless ad hoc network can be mainly classified into MANET (Mobile Ad hoc Network) and Wireless Sensor Network (WSN).

A mobile ad hoc network can be referred to as an infrastructure-less network of mobile devices connected with-out wires and which is continuously self-configuring. In a MANET each device will move independently in any of the direction and is free, and will therefore alter its linkage to any other devices at any point of time. Unrelated to its own use each must forward traffic, and thus be a router. One of the primary challenge concerning MANET is routing among the nodes. MANETs which has a networking that is routable in the environment on top of a Link Layer ad hoc network.

MANETs also has a peer to peer, self-forming as well as self-healing network. Wireless sensor networks (WSN), autonomous sensors distributed spatially to monitor environmental or physical changes, like pres-

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sure, temperature, sound, etc. and to co- operatively pass their data through the network to a main location and are sometimes called wireless sensor and actuator networks (WSAN). We are mainly concentrating on ZigBee, which comes under the category of wireless sensor networks. ZigBee is a WPAN (wireless personal area network) and which is standardized by a worldwide standard that defines a set of protocols for short-range wireless networking and for communication[1]. The frequency bands in which ZigBee-based wireless devices operate in 868 MHz, 915 MHz, and 2.4 GHz and 250 K bits per second is the maximum data rate. It is targeted mainly for battery-powered applications where the main requirements are low rate of date, economic and high battery life[1]. The wireless devices which are involved in any type of activity is very small number in counting in many ZigBee applications; in most case the time by which the device spending in a power-saving mode, can also know as sleep mode. As an effect, ZigBee enabled devices are capable for several years of being active before their batteries need to be changed.

ZigBee is ideally suited for the wireless control market which has so many ideal needs, because ZigBee is:

- Highly reliable
- Cost-effective
- Able to achieve very low power
- Highly secure
- An open global standard

This wireless networking standard may use into a market that is usually not covered by another wireless technologies (Figure 1). ZigBee provides cut down in data rates, while most wireless standards are striving to go faster and Zig fits on 8- bit microcontrollers, while other wireless protocols add more and more features. ZigBee looks to control a light or send temperature data to a thermostat, while other wireless technologies aim to deliver streaming high-definition media or to provide the last mile to the Internet.

ZigBee is designed to run for years, while other such technologies may works for hours or perhaps days with batteries and ZigBee products can typically provide decades or more of use, while other wireless technologies provide 12 to 24 months of shelf life for a product. Moreover, the slogan for ZigBee is also indicates the Wireless Control That Simply Work.

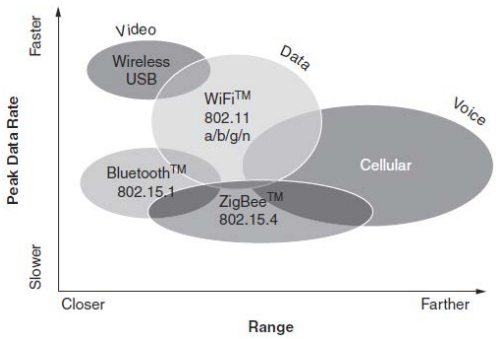

Figure 1. Wireless Technologies Compared.

Low power wireless mesh networking is provided by Zig-Bee and it can supports up to thousands of devices in a network, different from Bluetooth, UWB, and Wireless USB which are some other personal area network standards. Technologically controlled home construction and its automation[2], health care sector[3], smart power and energy[4], communication department, and other services such as retail sector are the diverse application areas to which ZigBee Alliance has wide advantages based on these characteristics. Home patient monitoring is one of the application of ZigBee and by wearable devices for example, a patient can measure the blood pressure and heart rate. The patient wears a ZigBee device that incorporates with a sensor that collects information related to health on a periodic basis[3]. The data is now wirelessly transmitted to a local server, initial analysis is performed there. The vital information is finally sent to the patients nurse or physician via the Internet for further analysis. The ZigBee standard was introduced and developed by ZigBee Alliance[5].

2. Literature Review on Routing Techniques

There are two categories of wireless ad hoc network. First one is mobile ad hoc networks and the second one is sensor networks[6]. In first case, there is no fixed topology and centralized management. So there are various conditions to structure a routing system for wireless ad hoc networks.

2.1 Mobile Ad-Hoc Networks

MANET is another type of ad hoc network composed of high capabilities mobile devices for data communication and supports different protocol like unicast, multicast and

hybrid routing. MANET[7] routing protocols can be further classified as proactive and reactive routing protocols. The topology information will be periodically updated by the proactive routing protocol, so this always has an optimized as well as updated routing scheme. OLSR[8] as well as DSDV[9] are the typical routing protocols which are proactive in nature. In short, the data transmission request is received through an application, routing protocol will be reactive and involves in the route finding scheme. Similarly, when it leads too delay in process to find out a path, it will not produce the control packet overhead, since no data to transmission. Reactive routing protocols include AODV[10], DSR[11], as well as TORA[12]. MANET routing protocols gives the optimal routing path where if there is proactive or reactive routing to the provided starting and reaching destination pair. But also, the necessary specified capacity of routing may be very high to save completely with provided routing paths in a device which is limited for resources[13].

In addition, it should exchange the control packets to furnish and to find out the proper routing as well as other transmissions of the same packets, the interferences of these packets may cause severe low rat and narrow bandwidth channels.

2.2 Routing Protocols Based on Communication Traffic Patterns

The communication traffic patterns can be categorized as any of one-to-many, many-to-one, any to any traffic patterns[14]. Every node will be a source and a destination of particular packets in case of the any-to-any traffic pattern. The many-to-one traffic pattern chooses one destination node and it collects the information from all the other devices in a network, where as in contrary to all these the one-to-many traffic pattern is implemented to transfer the packets to all other systems from a distinguished source node. Many-to-one and one-to-many traffic patterns are prominently shown in CTP[15] and RPL[16] as wireless personal area network protocols.

The representative tree routing protocol is Collection tree protocol (CTP) used in TinyOS[17]. A collection tree is built by considering the base station as its root so that all the sensor nodes can select their parent node in CTP. The expected transmissions count (ETX) is the routing metric of CTP, and a root has an ETX of 0. The ETX will be calculated as the sum of its parent ETX and its link ETX to its parent and the ETX of all neighboring device are maintained by the CTP so that it can choose the exact node having lesser ETX as that of the parent. Thus a node with sensor needs anything for transmission, which only needs to send the data in the packet to the parent. What follows is the simple repetition of the forwarding process whenever the data is received by the base station.

An IETF standard system of procedure which is based on CTP is referred to as RPL (IPv6 Routing system for Low Power and Lossy Networks). A destination oriented directed acyclic graph (DODAG) is generated by the RPL so which helps to control and validate traffic pattern of many to one, creates. Also, destination issues a single route request; upon which a DODAG in every device conforms the optimal routing path to end point that will be the entrance of a networking system. As compared with MANET routing protocols which makes it necessary to each and every single source for invoking the path finding to the very similar reaching point, this requires only single time route discovery. Thus DODAG will minimize all routes finding overhead as well as size of the routing format is needed.

Apart from all these observations, one of the most unavoidable advantages of these protocols is that by concentrating on the many-to-one and one-to-many traffic the overhead on route discovery is dramatically reduced. The in efficiency of routing path is very much evident as it needs to traverse along the tree topology. Even it support any to any pattern of traffic, it will hardly affect detour path as well as trafficking issues which is same as that of ZigBee.

2.3 ZigBee Wireless Sensor Networks

Routing techniques in ZigBee wireless networks mainly falls into two categories: the reactive routing protocol AODVjr (AODV junior) and ZigBee hierarchical or tree routing proto- col. All remaining routing techniques have their roots in these basic categories.

2.3.1 ZigBee Reactive Routing Protocol

The AODVjr (AODV junior)[18] acts as the basis of the reactive routing protocol in ZigBee, that is serves as the representative in the mobile ad hoc networks (MANET) for their routing. As that of similar prominent MANET systems for routing, the optimal routing path will be provided by the ZigBee reactive routing protocol by using discovery of routing on-demand to be implemented, between random source and destination pair.

AODVjr algorithms advantages lies primarily in energy saving and ample network performance. Only valid routes are maintained and all other paths unable to provide the correct routes for communication are avoided. The total routes are avoided and only the very next hop information is retained. It is even capable of a dynamic auto-start by-hop routing among the mobile nodes available in that network. It is a robust technique since it can notify the affected nodes and make them invalid in case of any breaking in the connection links. In time updates on network topologies and response sub channelization are also enabled. When adhoc network topology changes, for example, when a new node makes its entry to the network, AODVjr is capable of operating on non-circulation, and can also avoid fast convergent and infinite computational problems.

The main drawback is that, it needs the procedure for the discovery of a route to repeat for each pair which is undergoes communication. This makes a type of redundancy due to which overhead of discovery of path as well as the consumption of memory which is substantially hikes its levels proportional to increasing number of traffic sessions. Even in the spatially uncorrelated areas flooding of route discovery packets may interact with the transmission of packets from others, thus resulting in another typical bottleneck.

2.3.2 ZigBee Tree Routing

This is a distributed block addressing scheme which is seen through as a solution to address discovery of a route that is in overhead which include memory and bandwidth in ZigBee tree routing (ZTR). The nodes whether it is an intermediate or a source that determines whether to forward a packet of data to parent or any one of the children by means of finding and evaluating the address with destination, because each and every node is designed a hierarchical address[19].

A mechanism with distributed address allocation is used to allot the addresses in ZigBee networks. A network specific unique address is setup by a particular parent to its child on entrance of a particular proposed node in a network. Each and every main parent will be allocated with a definite sub block of address space, which is subsequently assigned to its children. Multiple parameters decide the sub-block size, as: the maximum number of children any parent has (Cm), maximum number of routers a parent has as its children Rm and finally the maximum depth in the spanning-tree network Lm. Once they are given to mention, the address sub-block's size and depth d, denoted as Cskip(d) can be computed as follows.

$$Cskip(d) = \begin{cases} 1 + Cm(Lm - d - 1), & Rm = 1 \\ \dfrac{1 + Cm - Rm - CmRm^{Lm-d-1}}{1 - Rm}, & Rm > 1 \end{cases}$$

A Cskip(d) value greater than zero denotes the ability of a node for allocating addresses and permitting other nodes to associate. Also, k-th router child as well as n-th end device child with a depth d+1 is allocated in a regular series, using the following equations:

$$A_k = A_{parent} + Cskip(d)(k - 1) + 1$$

$$A_n = A_{parent} + Cskip(d)Rm + n$$

Where k varies from 1 to Rm and n varies from 1 to Cm - Rm. The sensor nodes, which are framed as clean spanning network (tree model), particular nodes were identified and evaluated very quickly with their parent. Also, the nodes which are descendent in nature with a simple look up. Every device in ZigBee keeps a table with neighbor has all its related details in a one hop range of transformation, primary information being: Mac address, PAN identifier, device type and relationship.

Each individual ZigBee node has the capacity to work a routing based tree, without any use of additional space for memory or any kind of path discovery. When a transmission of data to its reaching point node with address D from a starting node (source) with address S with depth d is desired, it firstly performs a check to see if the source and destination address (S,D) follows below equation.

$$S < D < S + Cskip(d - 1)$$

The destination node will be one of the primary descendants of source node, if the equation is satisfied. Then source node directly forwards the data to one of its child node. Else, it transmits the data to its parent node.

The ability of any source node to send packets to any arbitrary destination node of a network without the cost of any route discovery overheads is the most benefit of ZTR. This efficiency distinguishes the aforesaid protocol for resource constrained devices to be implemented across variant applications. But regardless to the destination location, packets always follow the tree topology in ZTR. Even though it never required a route finding over-

head, it cannot always guaranteed a optimized routing protocol.

2.3.3 Hybrid Routing Algorithm

Proposes a mixed algorithm for routing to avoid flooding. The overhead is reduced by utilizing the hierarchical topology on hierarchical basis for the information to optimize the routing request broadcasting[21].

One of such routing is to balance the residential energy of the nodes with the energy utilization. But the optimized links are topology of hierarchical usually dependent and covering of routing makes the questionable routing efficiency.

2.3.4 Neighbor Table Based Routing Techniques

A shortcut tree routing algorithm is which reduces the routing cost of ZigBee tree routing with the help of a neighbor table, originally defined in ZigBee standards. While following the ZigBee tree routing algorithm, the algorithm suggests, if one can decrease the expense of the routing to particular destination, the most preferred method is forwarding the packet usually to the very near and closest node. However, the links in their method were still invariable and may lead to rapid decline of energy for some nodes[21].

An enhanced routing protocol for ZigBee/IEEE 802.15.4 wireless networks is proposed. For making the ZigBee Tree-based routing algorithm much more efficient, neighbor nodes are considered from where a local shortest path to the destination are calculated and the specific node having the shortest value is selected as next hop node. So such model is taken on the basis of Greedy algorithm, which is never become mandatory for us to make that we will receive altogether a very shortest path finally. The problem associated with this method is that the lifetime of nodes is not considered and load balancing over nodes is not evaluated[22].

A novel modified tree routing mechanism distinguished with an introduction of neighbor table. A successive improvement on the routing path is done by estimating the cost via each neighbor. It shows a comparable good performance system and commendably very low per packet transfer consumption and an excellent durability. But as this is also on the basis of two-hop neighbor scenario, same cannot be guaranteed in ZigBee networks; so this may leads to high memory overhead and energy[23].

The DFG-TR (Destination Family Group Tree Routing) was introduced to determine the relationship of forwarding and destination nodes that are closely neighbors. To decrease the routing cost to the definite destination, this technique will suggest the neighbor node as the next hop node. Since it can find neighbor node from which the destination family group exists. However, the life time of nodes and load balancing over nodes are still questionable[24].

Another routing system called ESTR (Energy-Efficient Shortcut Tree Routing) which also a tree based new type is suggested to reduce hop counts as well as to energy balancing in a network with the aid from the available neighbor tables. This also gives optimum low delay route on the basis of balancing load with the associated nodes. But this may lead to computational overhead[25].

The shortcut tree routing (STR) claims to significantly enhance the ZTR path efficiency with addition of a simple one-hop neighbor data. At the same time, ZTR uses tree links connecting the parent and child nodes only, STR exploits the neighbor nodes by allowing them for shortcut the routing pathway of tree model. Putting in other way, the smaller tree hops which are remained in the next hop node to the destination, which ever may be the type, as is a parent one, the children and or neighbor nodes, is always selected by a source or an intermediate node. This path selection in STR is done in sequential method by individual node and completely compatible with the standards for Zigbee. That accepts various routing protocols according to each node current condition. Another highlight being the feature that it does not requires any extra cost or any alteration in Zigbee standards like creation and maintenance mechanism of one-hop neighbor details etc...[26]

3. Performance Analysis

As it is commonly known a MANET is one special type of ad hoc network consisting of high capability autonomous nodes or devices for effective traffic routing and which supports many schemes like unicast, multicast and hybrid routing protocol schemes. MANET routing protocols are normally classified into proactive and reactive routing protocols. Whether or not it is the former or latter these protocols are capable of finding the best viable traffic path between the required nodes. But the problem comes with the fact that is the inability of

the small routing tables in the resource-limited devices to store the whole paths required. The exchange of control packets in the midway and the influence of these packets on other network transmissions specifically in the low rate and narrow bandwidth channels pose another threat. At the same time, the main advantage of the protocols based on the communication traffic patterns is their specialized ability to reduce the route discovery overhead. The many-to-one and one-to-many traffic are mainly taken into account here so as to accomplish the task. Even though they can support any variety combination of traffic pattern, the whole matter happens to be inefficient by traversing along the whole tree topology and problems such as detour path or traffic concentration problems like ZigBee tree routing are also observed commonly.

The ZigBee routing mainly falls into two categories: the reactive routing protocol AODVjr and ZigBee hierarchical or tree routing protocol. Whereas overhead for path finding and storage memory ingesting inefficiencies are the problems associated with AODVjr. General tree routing protocols, normally suffers from Deviation route problem and other monitoring to focus traffic problem finally resulting in an overall network performance degradation. STR (Shortcut Tree Routing) not only decrease the traffic load, it mainly focused on the associated tree links but also make available a routing path for the packets it is more preferable.

It provides comparable routing performance to AODV. The ZigBee applications are many, but that are demanding minimal memory and efficient routing it can utilize the extreme benefit of STR in various ways.

Here, we mainly concentrate on the ZigBee routing protocols and more focusing on the tree routing protocols. The experiment is conducted by using network simulator (NS2) and the graph evaluation of the parameters is done by using Xgraph. And also, IEEE 802.15.4 PHY/MAC protocols are being used to compare the two prominent ones under study namely, STR and ZTR. The graphs for packet delivery ratio, end to end delay and throughput were plotted.

The general parameter settings and their corresponding values are:

- Network size: 100m by 100m
- Number of nodes: 40
- PHY/MAC protocol: IEEE 802.15.4
- Propagation model: Two-ray
- Interface queue: Priority queue
- Simulation time: 10 sec, 15 sec, 20 sec, etc.
- Packet type: CBR
- Traffic type: Any-to-any/Many-to-one

Packet delivery ratio is the relative amount of packets that have successfully reached the destination from the sender entity as compared to the total number of packets that have been sent out to the receiver entity. Throughput or network throughput is a performance measure as done as a rate of successful messages delivered over a communication channel and end to end delay refers to the total time taken for a packet to be transmitted from source to destination across a network.

In ZTR, packets can be routed from the sender only along the tree topology to the destination even if the destination is nearly located. So, it will make more end to end delay and thus lower packet delivery ratio and throughput. When ZTR uses tree links connecting the parent and child nodes, STR proceeds by exploring through the neighbor nodes utilizing the fact that that there exist the neighbor nodes shortcutting the tree routing path in the mesh topology, which causes a lower end to end delay and a better packet delivery ratio. By following this strategy, STR make less in amount of the traffic load and also it bothered to the tree connection links to provides an efficient routing path.

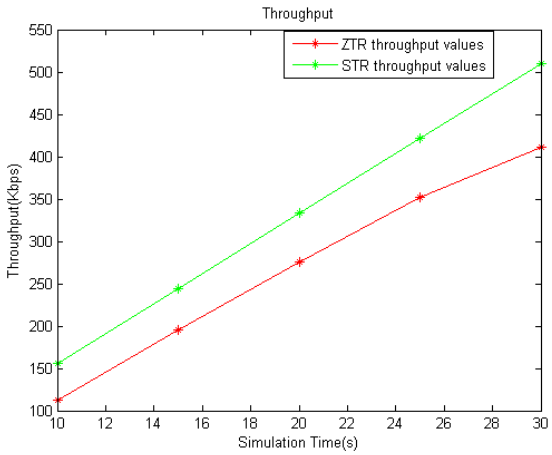

Figure 2. Throughput.

As compared to ZigBee tree routing, simulation results shows that shortcut tree routing have a better throughput (Figure 2), packet delivery ratio (Figure 3) and a lower end to end delay (Figure 4).

As a result, STR acquires a comparable routing performance with ZTR. But STR has the limitation that the

resulting routing path is not most favorable with respect to the in-between node hop distance. It should clearly maintaining self-evident of two hop neighbor information and also present the network with high protocol overhead, high node density. So, an enhancement to the STR along with the information about the geographic location of the nodes can be proposed as a future work.

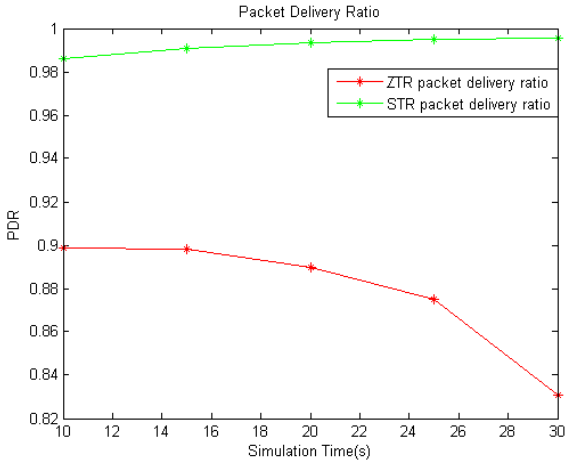

Figure 3. Packet delivery ratio.

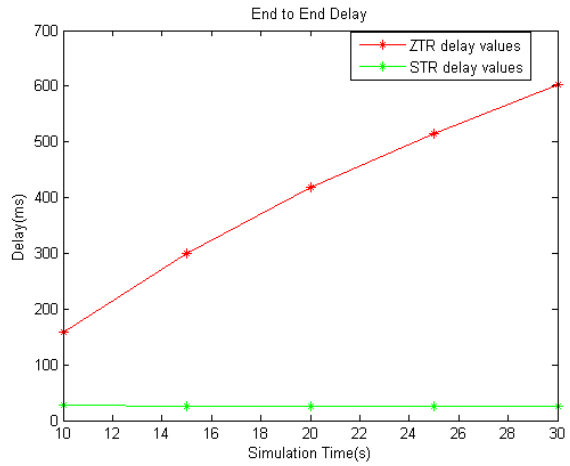

Figure 4. End to end delay.

That is, neighbor table is used to find the neighbor nodes within one hop range with the source node and from which the distance between the neighbor nodes and destination is used as one of the parameter to find the best route. If a route with minimum geographical distance is found, then the source node will transmit data to that particular neighbor node. Else, the network will follow the shortcut tree routing algorithm.

4. Conclusion

In traditional MANET routing protocols, the main bottleneck is the inability of the small routing tables in the resource-limited devices to store the whole paths required. The exchange of control packets in the midway and the influence of these packets on other network transmissions specifically in the low rate and narrow bandwidth channels pose another threat. In case of routing protocols based on the communication traffic patterns, a routing path happens to be inefficient because of its traversal through the whole tree structure unintentionally. Detour path as well as common traffic concentration problems like ZigBee tree routing is also observed commonly. The ZigBee routing mainly falls into two categories: the reactive routing protocol AODVjr and ZigBee hierarchical or tree routing protocol, whereas overhead for route discovery problem and over consumption of memory inefficiencies are the problems associated with AODVjr.

General tree routing protocols, normally suffers from quite many issues such as Detour path problem and other traffic problems finally resulting in an overall network performance degradation. STR (Shortcut Tree Routing) not only provides the best routing path viable for the packets but also drastically reduces tree link associated traffic load. It provides comparable routing performance to AODV. But STR has the limitation that the final path obtained for routing May not always optimal with respect to the effective hop-to-hop distance. So, an enhancement to the STR along with the information about the geographic location of the nodes can be proposed as a future work.

5. References

1. Farhani S. ZigBee Wireless Networks and Transceivers. Newness Elsevier USA. 2008; p. 1-364. Crossref.
2. Han DM, Lim JH. Smart Home Energy Management System Using IEEE 802.15.4 and ZigBee. IEEE Transaction. Consumer Electronics. 2010 Oct; 56(3):1403-10. Crossref, Crossref.
3. Chen SK, Kao T, Chan CT, Huang CN, Chiang CY, Lai CY, Tung TH, Wang PC. A Reliable Transmission Protocol for ZigBee-Based Wireless Patient Monitoring. IEEE Transaction. Information Technology in Biomedicine. 2012 Nov; 16(1):6-16. Crossref PMid:21997287.
4. Yi P, Iwayemi A, Zhou C. Developing ZigBee Deployment Guideline under Wi-Fi Interference for Smart Grid

Applications. IEEE Transaction on Smart Grid. 2011 Nov; 2(1):110-20. Crossref.
5. Gislason D. ZigBee Wireless Networking. Newnes. Elsevier USA. 2007.
6. Biradar RV, Patil VC, Sawant SR, Mudholkar RR. Classification and comparison of routing protocols in wireless sensor networks. Special Issue on Ubiquitous Computing Security Systems Journal. 2009 Aug; 4:1-8.
7. Kiess W, Mauve M. A Survey on Real-World Implementations of Mobile Ad-Hoc Networks. Ad Hoc Networks. 2007 Apr; 5(3):324-39. Crossref.
8. Clausen T, Jacquet P. Optimized Link State Routing Protocol (OLSR). Internet Request for Comments. 2003. Crossref.
9. Perkins CE, Bhagwat P. Highly Dynamic Destination Sequenced Distance-Vector Routing (DSDV) for Mobile Computers. SIGCOMM Computer Communication Review. 1994 Oct; 24(4):234-44. Crossref.
10. Perkins C, Royer BE, Das S. Ad-Hoc on-Demand Distance Vector Routing. Internet Request for Comment. 2003. Crossref.
11. Johnson DB, Maltz DA. Dynamic Source Routing in Ad Hoc Wireless Networks. Mobile Computing. 1996; 353:153-81. Crossref.
12. Park VD, Corson MS. A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks. Proceedings of the IEEE INFOCOM'97. 1997; p. 1405. Crossref.
13. Chen BR, Reddy KKM, Welsh M. Ad-Hoc Multicast Routing on Resource Limited Sensor Nodes. Proceedings of the Second International Workshop on Multi Hop Ad Hoc Networks from Theory to Reality. 2006; p. 87-94. Crosssref.
14. Wheeler A. Commercial Applications of Wireless Sensor Networks Using ZigBee. IEEE Communication Magazine. 2007 Apr; 45(4):70-7. Crossref.
15. Gnawali O, Fonseca R, Jamieson K, Moss D, Levis P. Collection Tree Protocol. Proceedings of the Seventh ACM Conference Embedded Networked Sensor Systems (SenSys). 2009; p. 1-14. Crossref.
16. Ko J, Terzis A, Dawson-Haggerty S, Culler DE, Hui JW, Levis P. Connecting Low-Power and Lossy Networks to the Internet. IEEE Communications Magazine. 2011 Apr; 49(4):96-101. Crossref.
17. Levis P, Madden S, Polastre J, Szewczyk R, Whitehouse K, Woo A, Gay D, Hill J, Welsh M, Brewer E, Culler D. Tiny OS: An Operating System for Wireless Sensor Networks. Ambient Intelligence 2005. PMCid:PMC1895185.
18. Chakeres ID, Klein-Berndt L. AODV Simplified. ACM SIGMOBILE Mobile Computing and Communication Review. 2002; 6(3):100-1. Crossref.
19. Ran P, Sun MH, Zou YM. ZigBee Routing Selection Strategy Based on Data Services and Energy-balanced ZigBee Routing. Proceedings of the 2006 IEEE Asia-Pacific Conference on Services Computing (APSCC'06). 2006 Dec; 82(1):400-4. Crossref.
20. Lin Z, Meng MOH, Liang H. A Route Discovery Method based on Limited Flooding in ZigBee Networks. China: Proceedings of the IEEE International Conference on Automation and Logistics. 2008; p. 3039-44.
21. Kim T, Kim D. Shortcut tree routing in ZigBee networks. International symposium on wireless pervasive computing. 2007 Feb; 3(9):42-7. Crossref.
22. Xu X, Yuan D, Wan J. An Enhanced Routing Protocol for ZigBee/IEEE 802.15.4 Wireless Networks. IEEE second International Conference on Future Generation Communication and Networking. 2008 Dec; 8(97):425-9.
23. Zhang S, Zhou H. An Improvement of ZigBee Tree Routing in the application of Intelligent Irrigation. Intelligent System Design and Engineering Application (ISDEA). 2010; 2.
24. Ahn S, Ko D, Kim B. Energy-efficient Tree Routing Algorithm-based Destination Family Group in ZigBee Networks. IEEE Fourth International Conference on Sensor Technologies and Applications. 2010 Apr; 16(5):524-8. Crossref.
25. Khatiri A, Mirjalily G. Energy-Efficient Shortcut Tree Routing in ZigBee Networks. IEEE fourth International Conference on Computational Intelligence Communication Systems and Networks. 2012; 6(12):673-8. Crossref.
26. Kim T, Kim SH, Yang J, Yoo S, Kim D. Neighbor Table Based Shortcut Tree Routing in ZigBee Wireless Networks. IEEE Transactions on Parallel and Distributed Systems. 2014 Mar; 25(3):256-67.