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Dynamic Tree Routing Protocol DTR in Zigbee based Wireless Sensor Network

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□ ABSTRACT □

In many wireless sensor network applications like forest fire detection and environment monitoring, battery powered sensors are often randomly distributed in monitoring area, and data packets are usually sent from those sensors toward network's main coordinator which acts as a gateway to the monitoring center. Considering such network routing requirements, and the limited sensor energy, we proposed our Dynamic Tree Routing Protocol (DTR), which is an improved version of Modified Zigbee Hierarchical Tree Routing Protocol (MZBR), this protocol dynamically distributes traffic to coordinator in each hop according to specific quality factor depends on the depth, Link Quality Indicator (LQI), and the remaining energy of receiving sensor. The simulation results obtained from Network Simulator Version 2 (NS2) showed better distribution of energy consumption and improvement in network lifetime, while keeping good packet delivery ratio and end to end delay compared with On Demand Distance Vector AODV and Modified Zigbee Hierarchical Tree Routing MZBR Protocols.

Keywords Wireless Sensor Networks, Hierarchical Tree Routing, Dynamic Tree Routing, Zigbee, IEEE802.15.4.

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بروتوكول التحويل الشجري الديناميكي DTR في شبكات الحساسات اللاسلكية المعتمدة على تقنية ذكبي

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□ ملخّص □

في كثير من تطبيقات شبكات الحساسات اللاسلكية كتطبيقات كشف حرائق الغابات ومراقبة البيئة، يتم توزيع الحساسات اللاسلكية المعتمدة على البطاريات عشوائيا في منطقة المراقبة، وغالبا ما يتم ارسال البيانات من هذه الحساسات باتجاه منسق الشبكة الرئيسي الذي يعمل كبوابة عبور الى مركز المراقبة.

بأخذ متطلبات التحويل لمثل هذه الشبكات بالحسبان، ومحدودية طاقة الحساسات، قمنا بتطوير بروتوكول التحويل الشجري الديناميكي (DTR) والذي هو تحديث لبروتوكول التحويل الشجري المعدل في ذكبي (MZBR)، يقوم هذا البروتوكول بشكل ديناميكي بتوزيع الحمل المتجه الى منسق الشبكة في كل قفزة بالاعتماد على معامل جودة محدد يعتمد على العمق، مؤشر جودة الوصلة (LQI)، وعلى الطاقة المتبقية في الحساس المستقبل.

أظهرت النتائج التي حصلنا عليها باستخدام محاكي الشبكات الإصدار الثاني (NS2) توزيع أفضل لاستهلاك الطاقة وزيادة في زمن حياة الشبكة، مع الاحتفاظ بمعدل تسليم بيانات وزمن تأخير جيد مقارنة بالبروتوكول AODV وبروتوكول التحويل الشجري المعدل في ذكبي.

الكلمات المفتاحية: شبكات الحساسات اللاسلكية، التحويل الشجري، التحويل الشجري الديناميكي، تقنية ذكبي، IEEE802.15.4.

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Introduction

Zigbee Hierarchical Tree Routing ZTR is very simple and resource conservation protocol, this protocol follows child-parent relationship for routing packets, that means if the sink sensor is two hops near the sending source, but in a different branch of tree, and the source sensor is many hops away from the network main coordinator, packets must be first forwarded to the main coordinator, then to that sink. This method of routing increases delay and reduces network throughput[1].

Many developments to Zigbee Tree Routing protocol have been carried out to overcome this problem by enabling network to route the packets directly to its destination without passing through main coordinator, one of successful improvements to Zigbee Tree Routing protocol is Shortcut Tree Routing (STR) [2], this protocol enables routing packets between any two sensors without pathing through main coordinator, and with no extra overhead, so this protocol performs well in peer to peer (P2P) traffic pattern with comparable performance with AODV protocol, but this protocol suffers from detour traffic concentration problem and it couldn’t always select the optimal hop-count path as mentioned in reference [3] which proposed an enhanced version (ESTR) to overcome this limitations, Another one is Modified Zigbee Tree Routing Protocol MZBR [4], which enables sensors to forward packets to one of its neighbors if the destination is descendent of that neighbor by using neighbor table information, to reduce hop-count to the destination in P2P traffic, but this protocol performs like Default Zigbee Tree routing Protocol ZTR in many to one traffic towards main coordinator, also ISTR protocol [5] makes an effort to reduce hop-count and to address the traffic concertation problem in Zigbee Tree Routing, by using the size of neighbors buffer as a metric in neighbors table, the simulation results showed a 20% to 30% reduction of end to end delay and good improvement in packet delivery ratio compared to default Zigbee Tree Routing protocol. NP-ZBR, OI-ZBR, NI-ZBR [6] are an improved versions of Zigbee Routing protocol, these protocols try to reduce energy consumption by controlling the propagation of broadcast control packets which used to update full path routing table, or eliminating the necessity of using broadcast control packets if the address of destination node in the range of neighbor node.

None of the previous Protocols had addressed the situation when all sensors have to forward packets to the main coordinator, using the only child-parent hierarchical path or most suitable reduced hop-count path, which causes serious drain of energy resource of the sensors belong to the path toward main coordinator, which in turn reduces the network life time, also full path table driven routing protocols like Proactive Routing Protocols (AODV) and Reactive Routing Protocols like (DSR, DSDV) are supporting many paths between any two Sensors, and they are much better in selecting suitable path, but they are much resource consumers, because they use many broadcast command packets to find and maintain the routing table, also when packets always flow from sensor to the main coordinator, they may use same path many times, thus they are unsuitable for resource-constrained sensors.

In order to support many applications requirements Zigbee uses tree routing, and on demand routing (AODV), and offer the availability to combine them optionally. Recently Zigbee pro has developed the Multi Peer to Peer (MP2P) protocol with source routing to support many to one traffic pattern, but according to reference [7] which made a good comparison of Zigbee routing protocols in different traffic pattern, Zigbee MP2P routing suffer from poor performance in P2P traffic, because all traffic must pass thought network main coordinator, also it require all node to send root request command to the main shared destination called "concentrate", where's single path Shortcut Tree Routing STR performs good in P2P traffic, and it's performance is comparable to AODV, but this protocol also may use the alternative reduced hop-count path in many to one traffic, so to support wireless sensor networks where traffic often follow many to one pattern, and in the same time keep the pros and successful improvement achieved by enhanced versions of Zigbee tree routing protocols in supporting P2P traffic, we decided to make benefit from the modified version of this protocol MZBR, and improve its many to one traffic support by enabling multi path towards sink, in order to distribute traffic and energy consumption, and prolong network life time, with no extra broadcast control packets.

Our Dynamic Tree Routing DTR protocol, doesn't record and maintain full path toward main sink, it only uses one hop neighbor table information, and it dynamically select next hop towards main coordinator in each hop, considering parent quality as a reference, to distribute packets along many paths from source nodes to the main coordinator.

Research importance and goal

Resource conservation routing is a very important task in WSN, especially when sensors are battery powered, and there is a huge effort and cost to replace their batteries. Zigbee Tree Routing is tiny and energy conservation protocol, but when sensors sending data to the network main coordinator, there is a chance to frequently use the same default hierarchical or reduced hop-count path, until consuming all energy of sensors belong to it, which reduce the network lifetime, so to prolong the network life time and to avoid sending all data in the same default or alternative path, our protocol aims to distribute energy consumption by dynamically and in each hop forwarding data to a neighbor when its overall quality (link quality, remaining energy, hop count to main coordinator) is larger than of the default next hop senor, by using only one hop neighbors table information, with no extra overhead broadcast control packets, also our protocol aims to avoid sending more data to neighbor if sensor detects that there is no activity of that neighbor in certain period of time, to reduce dropped packets in the network.

Research method

We used discrete event Network Simulator Version 2 (NS2) to test and analyze our protocol in various configuration, because NS2 is open source and it provides variety of modules to support networking research (IEEE802.11, IEEE802.15.4, TCP, UDP, IP, AODV, DSR, DSDV,…), and many of scientific researches depend on it.

On Demand Distance Vector AODV Protocol

This protocol belongs to reactive routing category, this mean the protocol searches for optimal path between source and destination only when source node want to transmit and there is no path entry between source and destination in source routing table.

The path search procedure begins from source node by flooding packet request (PREQ) in the network until it reaches destination node from multiple paths having deferent cumulative costs, then the destination node selects cumulative least cost path to reply with (RREQ) packet to the source node, where the cost of link between any two nodes is computed by using the probability of delivering packet in that link.

In case of link failure the intermediate nodes which detect the failure sends failure message to the source node, informing it to begin another search procedure.

Zigbee Hierarchical Tree Routing Protocol

In Zigbee multi hop network, the main coordinator begins the network, determines max allowed children's (Cm) and routers (Rm) each coordinators or sub coordinators (routers) can has, also it determines the max depth allowed in the network (Lm),

The depth of main coordinator is equal zero, first children has a depth equal to one and so on. Sensors obtain their depth and address when they join the network.

Zigbee tree routing uses Distributed Address Assignment (DAA) addressing schema, the main and sub coordinators uses Lm, Cm, Rm to calculate C_{skip} function which determines the range of addresses each coordinator can assign to its children, depending of coordinator's depth according the following formula:

$$C_{skip}(d) = \begin{pmatrix} 1+Cm*(Lm-d-1)\ if\ Rm=1 \\ \frac{1+Cm-Rm^{Lm-d-1}}{1-Rm}\ if\ Rm<>1 \end{pmatrix} \text{ Eq } (1)$$ [1]

If C_{skip} is equal to zero this mean that coordinator couldn't have any children and it is in the border of network.

If the coordinator has depth = d and it's address is A_parent the number of total allowed children is n where $1 \leq n \leq (Cm - Rm)$, then the address of its nth order Full Functional Device (FFD) children A_child can be calculated with the following formula

$$A\_child = A\_parent + (n-1) * C\_skip\ (d) + 1 : n = 1 \text{ Eq } (2)$$

$$A\_child = A\_parent + (n-1) * C\_skip\ (d)\ : n > 1 \text{ Eq } (3)$$

The address of Reduced Function Device (RFD)

$$A\_child = A\_parent + Rm * C\_skip\ (d) + n \text{ Eq}(4)$$

When any sensor with address (A) has data to send or forward, it firstly chick the destination address (D), if the address is one of its direct children address or it's one hop neighbor address, it sends packet to that children or neighbor directly, else if sensor A detects that destination is descendant sensors in tree structure by using Equation (5), it forwards the packet to its suitable children, else it sends packet to the parent.

$$A < D < Cskip\ (d-1) \text{ Eq}(5)$$

Dynamic Tree Routing Protocol DTR

When sensors have to send packets to the main coordinator, the packets will always follow the child parent relation when using Zigbee hierarchical tree routing, this mean same path every time.

In dynamic tree routing, sensor don't have to build and maintain full path routing table, and no extra overhead control packets is required, DTR uses only one hop neighbor table, and in each hop the sensor decides best next hop according Depth and Quality Factor ($Quality_f$) which depends mainly on neighbor's residual energy and Link Quality Indicator ($Link_{LQI}$) between sensor and its neighbor, we calculate this factor with the following formula

$$Quality_f = (\lambda_{er} * \frac{Neighbour_{energy}}{Max_{energy}} + \lambda_{qr} * \frac{Link_{LQI}}{Max_{LQI}}) \text{ Eq}(6)$$

Where:

$\lambda_{er} + \lambda_{qr} = 1.$

λ_{er} : Energy Factor.

λ_{qr} : Link Quality factor.

Here we can choose energy and link quality factors according our needs, as if we more interested in distributing energy consumption, we must make energy factor larger than link quality factor, to increases the available baths and to make path selection more dynamic, as we will see in later tests.

Taking parent quality as a reference quality $Quality\_ref$, and parent depth as reference depth $Depth\_ref$, when sensor have packets to send to the main coordinator, it first calculate parent quality according equation (6), then it searches it's one-hop neighbor table about parent neighbors who have better quality with equal or smaller depth to forward packet to it.

When parent energy falls down critical level called energy danger E_{Danger}, and in order to save parent energy, and extend network life time, sensor stops searching parents neighbor, and begin to search it's same depth neighbors, and in order to prevent loops we make sending sensor's energy as reference quality, and packet must be forwarded to the neighbor who has the least residual energy above the reference, and link quality larger than LQI_{min}, in order to make more available paths.

Each sensor in the network updates its one hop neighbor table information every time it receives beacons or data packets, we also make benefit from overhearing packets, when sensor sends packet to its neighbor, the neighbor must forward this packet to next hop if it is not the final destination, and the sending sensor must sense overhearing packet from that neighbor when it forwards the packet in a certain period of time called Δt, if the sensor didn't hear any activity from its next hop neighbor during this period, it consider the link to this neighbor is unavailable or the neighbor is exhausted (in active or passive scan, busy, orphaned, collision, …), and it stops sending more packets to this neighbor until it sense new activity from it.

In all situation and in every hop when parent energy above or below energy danger, when node fails to find more suitable next hop, it forwards the packet to its parent.

Link Quality Indicator LQI

It express the strength or quality of received signal, and according to IEEE802.15.4 standard, it may calculated using signal power or signal to noise ratio, or a combination of them, and its value must uniformly distributed between [0..255] according minimum and maximum quality detectible by receiver [8]. We used a signal power and SNR to calculate LQI separately, and we selected the minimum value between them as link quality.

DTR Protocol Flow Diagram

When a sensor receives a beacon or data packet, if the packet is an overhear packet, it adds the sending sensor as neighbor if it is not yet in its one-hop neighbors table, and updates that neighbor information, else if the packet is for this sensor and this sensor is the final distinction for packet, then it immediately receives the packet, and if the final destination is the main coordinator, then the sensor forwards this packet to one of its neighbors according its Quality Factors as mentioned before, and if the final destination is other peer sensor in the network, then Modified Tree Routing is applied to forward the packet to the appropriate neighbor sensor, and all Situations whenever any sensor in the network sends a beacon or data packet to the main coordinator, then all sensor's neighbors will update their one hop neighbor table from overhearing data packets including quality factor of each neighbor, also all other one hop neighbors beside sensors which belong to routing path will updates their one hop neighbors information.

The following figure represent the flow diagram of packet movement from the time of receiving packet to the time of forwarding it, when using our Dynamic Tree Routing Protocol.

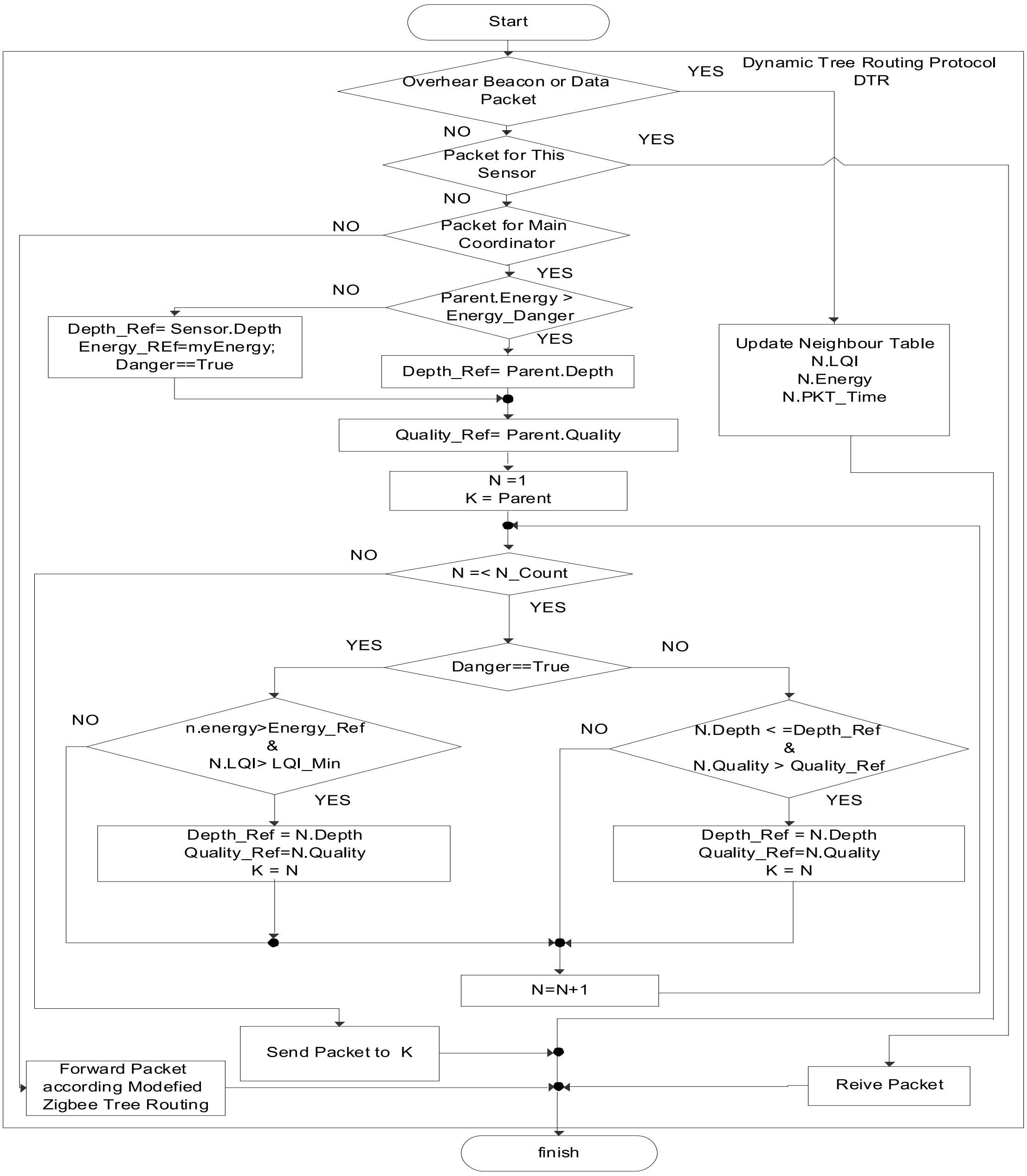

Figure (1) Diagram of DTR routing protocol in MP2P traffic pattern

Performance evaluation

We evaluated DTR in various performance metrics, and various scenarios had adopted to analyze and compare protocol performance in case of nodes failure, changes in energy and quality factors.

Network simulator version 2 with IEEE 802.15.4 module are used for comparing DTR with MZBR and AODV. We used general parameters settings as summarized in table (1) unless modified sittings are mentioned. we reply each test 10 times and take an average value of each performance metric every time we use random deployment of sensors, and in all random simulations, the main coordinator is placed in the center of network.

Simulation Parameters

To obtain many paths toward main coordinator, and to reduce beacon collisions in the network, we don’t configure any sleeping reduced end functional devices, all sensors is configured to be Full Functional Devices (FFD) with routing capability, some of them periodically send beacons and others don't. also we configured main coordinator to have larger initial energy (100 joule) to be able to handle all traffic coming from sensors, we also configured power consumption values as in the Chipcon CC2420 [9].The following table shows the general simulation parameters.

Table (1) General Simulation Parameters

Simulation parameters	Value	Simulation parameters	Value
Topology formation	Fixed, Random	Maximum Children MC	4 , 7 , 15
Number of nodes	11,101	Maximum Depth Lm	4 , 7
Network Size	100*100 m^2	Energy factor	0.75
PHY/MAC protocol	IEEE 802.15.4	LQI factor	0.25
Link model	Tow ray ground	Energy Danger	0.39 % Initial energy
Routing protocol	MZBR/AODV/DTR	Time Deference Δt	1 Sec
Simulation time	300 -500 s	Packet interval	1.2 Sec
Association duration	0–68 s	LQI_min	150
Transmission duration	68–300 s	Initial energy	1 , 3 Joule
Transmission Range	20 m	RxPower	35.28e-3 Watt
Packet type	CBR	TxPower	31.32e-3 Watt
Packet size	90 bytes	IdlePower	712e-6 Watt

Performance metrics

The performance metrics like, hop count, end to end delay, packet delivery ratio PDR, network lifetime, are used to evaluate and compare DTR,MZBR,AODV Protocols.

1.1.1 Packet Delivery Ratio PDR

The percentage of all successfully received packet Rn to all sent packets Sn,

$$PDR = \left(\sum_{I=0}^{N} Rn_i \,/\, \sum_{i=0}^{N} Sn_i \right) * 100$$

Where :

N : packet id.

Sn_i : = 1 if packet with id equal to i has Sent, else Sn_i = 0.

Rn_i : = 1 if packet with id equal to i has received correctly, else Rn_i = 0.

1.1.2 Packet End to End Delay

the average time duration from sending packets and receiving them correctly in destination

$$E2E\_D_{AVG} = \frac{1}{Rn} \sum_{i=0}^{Rn} (Rt_i - St_i) \quad \text{Eq}(7)$$

Where:

Rn : the number of successfully delivered packets.

Rt_i : the time when packet with id equal to was received.

St_i : the time when packet with id equal to i was sent.

1.1.3 Packet Jitter

The average value of difference in each packet end to end delay from the average value $E2e\_D_{AVG}$.

1.1.4 Average Remaining Energy

The sum of remaining energy in each sensor E_i to the sensors count n.

$$Avg_E = \frac{\sum_{i=1}^{n} E_i}{n} \quad \text{Eq}(8)$$

1.1.5 Network Lifetime

There are many confederation and different metrics to calculate network life time, some of these metrics are [10]:

- When first node totally loses its energy in network.
- When percentage number of sensors lose their energy.
- When no node can communicate or send packets to its destination.

In this research we will consider first metrics.

1.1.6 hop count

The average number of all intermediate router that packets move through until they reach their destination.

1.1.7 Standard Deviation SD

Standard Deviation (SD) expresses how mush certain set of data samples x_i is separated from its average value x_{avg} [11].

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - x_{avg}\right)^2}{n-1}} \quad \text{Eq}(9)$$

Where:

n : is the number of data set samples.

1.2 simulation scenarios

We used various simulation scenarios, to realize that our protocol DTR works as required, we begin from basic scenario with fixed multi-hop network of few sensors, to a larger multi-hop network with randomly distributed sensors sending many to one constant bit rate traffic towards main coordinator, we between our

1.2.1 Basic testing for Dynamic Tree Routing Protocol

The network works in beacon enabled mode, all sensors are full functional devices except sending sensor is Reduced Functional Device RFD, they capable only in sensing and sending packets, each sensor in the network sends beacon every 979.2 MS, the network were organized so that sending sensor have enough neighbors in different depth to forward packets to. For this simulation we used general parameter defined in table (1), only modified parameter appear in the following table (2)

Table (2) modified parameters for basic testing

Simulation parameters	Value	Simulation parameters	Value
Topology formation	Fixed	Simulation time	1120 s
Position of the main coordinator	Border	Association duration	0–50 s
Maximum number of children (MC)	5	Queue Length	100 packets
Maximum Depth (Lm)	4	Packet interval	0.2 sec
Number of nodes	11	Initial energy	3 Joule

In this simulation, sensor 8 sending CBR traffic toward network main coordinator (Sensor 0). The topology of the network is shown in the following figure (2).

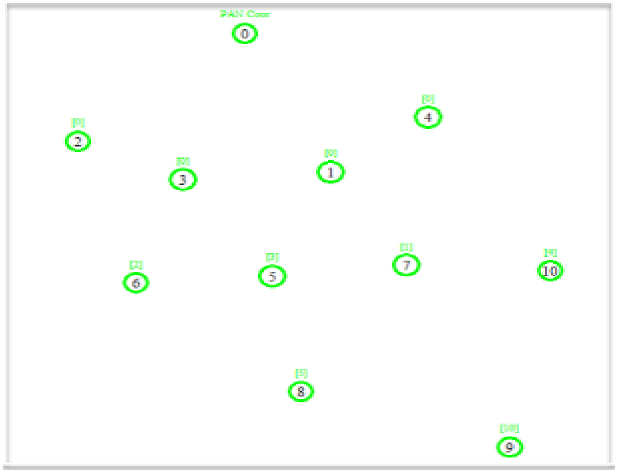

Figure (2) Fixed Network topology

1.2.1.1 Network Lifetime

Main coordinator begins the network, and when all sensors join this network, sending node (sensor 8) will have a depth equal 3, its parent is sensor 5, this mean all traffic from sensor 8 to main coordinator will follow this path when using Modified Zigbee Hierarchical Tree Routing, until any sensor in the path changes its parent.

The following figure (3) shows network life time when using DTR,MZBR,AODV protocols, considering that the life time of the network ends when the first sensor in the network totally loses its energy.

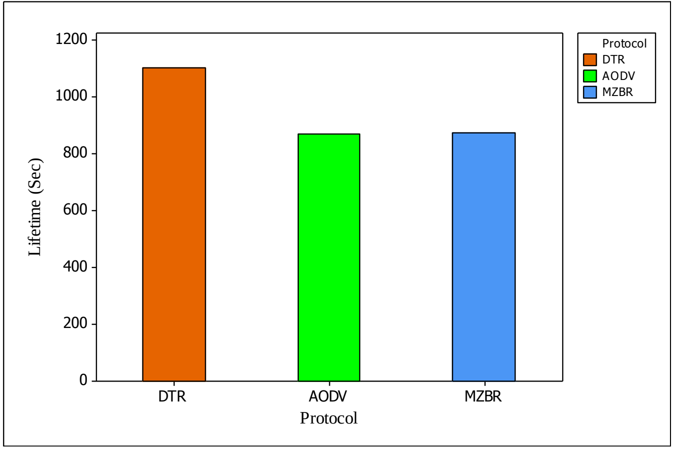

Figure (3) Compare network lifetime

The list of routing sensors R which form the routing paths are shown in the following table (3).

Table (3) Routing path compare in fixed network

		Packets	Source	R1	R2	Dist	
MZBR	$Path_1$	4102	8	5	3	0	
	$Path_2$	1162	8	7	1	0	
AODV	$Path_1$	4072	8	6	3	0	
	$Path_2$	1229	8	7	4	0	
DTR	$Path_1$	1788	8	5	3	0	
	$Path_2$	1316	8	5	1	0	
				R1	R2	R3	Dist
	$Path_3$	2149	8	9	10	4	0

MZBR still using same default hierarchical path (Path$_1$) until the sensor 5 which is the parent node of sensor 8 totally loses its energy, and the life time of the network is ended in the time /872.2106/ sec as shown in table (3) when using this protocol, but we continue to notice network behavior for comparison reasons.

Then sensor 8 search for another parent, and re-associate with sensor 7, forming second default hierarchical path (Path$_2$), and the sensor continue sending packets through this new path .

AODV don’t limited to use the hierarchical path if it is not the most suitable one which have minimum cost, the most suitable paths are (AODV Path$_1$, AODV Path$_2$) as shown in table (4), nor of them is the default hierarchical path, also AODV didn’t distribute traffic load between these two paths, it sent /4072/ packets through first path, and only /1229/ packets through second one, causing energy degradation of sensors belonging to the first path.

When using DTR, in each hop, whenever the sensor find a neighbor with depth equal or less parent depth (to reduce hop count), and with best quality tacking parent quality as reference, it send packet to it, making path selection more dynamic, and sensor may only use path with hop count larger than default hierarchical path hop count only when parent is exhausted or its energy becomes below energy danger threshold.

We notice that DTR more equally distributed the traffic load between available main paths (Path1,path2), it sent /1788/ packets through first path, and /1316/ packets through second one, and began to use emergency path (path3) when the energy of sensor 5 became below energy danger to save its energy and to prolong network life time as shown in figures (3), where all sensor still alive till the time /1098.191360/ seconds as shown in table (4), saving /20.979 %/ of network lifetime compared with AODV and /20.577 %/ compared with MZBR. The remaining energy of each sensor in the end of simulation is shown in the following table (4).

Table (4) remaining energy in the end of simulation

	MZBR		AODV		DTR	
Sensor	Time	Energy	Time	Energy	Time	Energy
1	1119.852	0.159867	1119.852	0.266198	1119.887424	0.445585
2	1119.824	1.36868	1119.831	0.76422	1119.887424	1.707804
3	1119.824	0.076513	1119.831	0.242168	1119.887424	0.76826
4	1119.824	1.586952	1119.831	1.435959	1119.818816	0.878635
5	872.2106	0	1055.921	0	1119.300736	0
6	1048.216	0	867.8014	0	1119.826048	0.318634
7	1119.852	0.160605	1119.852	0.765015	1098.19136	0
8	1119.809	0.497492	1119.811	0.512945	1119.887424	0.49112
9	1119.802	1.368149	1119.803	1.392544	1119.826048	0.507094
10	1119.852	1.872462	1119.852	1.67713	1119.852416	0.854453

1.2.1.2 Effect of Energy Factor on Network Lifetime

In the following figure (4) we show the effect of increasing energy factor from 0 to 1 on the network life time.

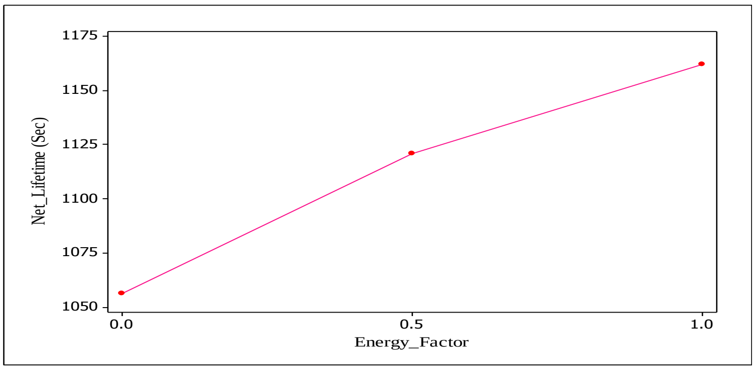

Figure (4) effect of energy factor in network lifetime

When energy factor is equal to zero then the overall quality is based only on link quality indicator, and if the link quality to parent is the best most of time, the overall quality will not change when parent energy decreases until it reaches the energy danger threshold, making less chance to distribute traffic. However the life time of the network still larger with comparable with MZBR and AODV as shown in figure (4), and when the energy factor is increased, the overall quality varies more rapidly according how many times each sensor send or receive packets, making larger chance for a sending sensor to distribute traffic to its neighbors.

1.2.1.3 Link failure

To test the protocol immunity in case of link failure, we halted some of the sub coordinators which belong to the main routing paths for specific durations as showed in table (5).

Table (5) Sub coordinators halt time durations

Sensor	From	TO		Sensor	From	TO
5	120	150		3	130	170
1	200	235		7	210	250

The following figure (5) shows the packet delivery ratio when using each protocol.

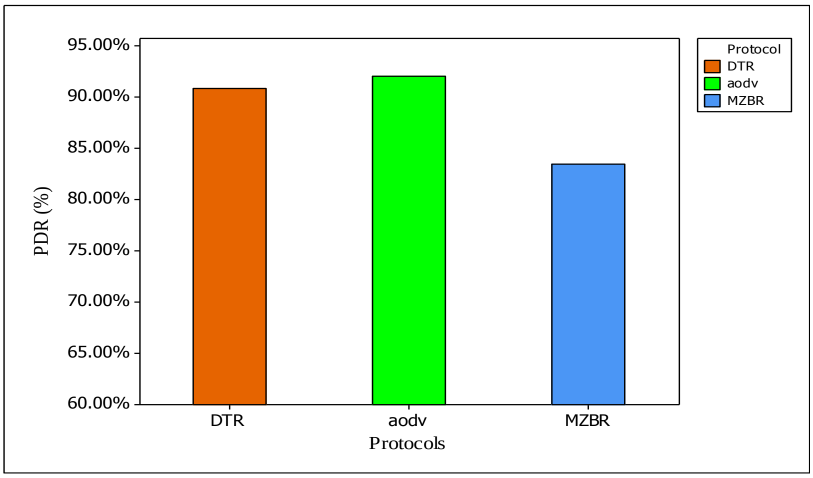

Figure (5) immunity of protocols in case of sub coordinators failure

and the following table (6) shows the main routing paths used by each protocol

Table (6) routing paths compare in case of node failure

		Packets	Source	R1	R2	Dist	
MZBR	$Path_1$	756	8	5	3	0	
	$Path_2$	328	8	7	1	0	
AODV	$Path_1$	374	8	6	3	0	
	$Path_2$	802	8	6	0	0	
DTR	$Path_1$	612	8	5	3	0	
	$Path_2$	335	8	5	4	0	
	$Path_3$	85	8	7	1	0	
				R1	R2	R3	Dist
	$Path_4$	36	8	9	10	4	0
	$Path_5$	89	8	6	5	2	0

We notice from figure (5) that the dropped packets in DTR are nearly equal to dropped packets in AODV, and less than Modified Zigbee Tree routing because by using DTR and when sensor stops receiving beacons from its parent through duration larger than Δt, or when sensor don't sense overhearing packet from its parent after sending packet to it, the sensor adjusts parent quality to a low value making more chance to forwards packets to neighbors, as shown in table (6), while in Modifies Zigbee Tree routing the sensor will continue sending packets to its parent resulting in more dropped packets.

1.2.2 Random Test

In this test, we randomly spread /100/ sensors in the monitoring area, the main coordinator is always in the middle of the network, and we repeat each random test 10 times and take an average value for each performance metric, we set Cm=7, Lm=6 in order to enlarge address space to be capable to accept all sensors in the network. We configured /8/ random sensors to sends CBR traffic toward main coordinator with packet interval equals to /1.2/ second, and /20/ other random sensors to send low load CBR traffic with interval equals to /25/ second.

1.2.2.1 General performance metrics

The following table (7) shows general performance metrics used for comparing protocols.

Table (7) general performance metrics in random test

	AODV	MZBR	DTR
E2E_D (Seconds)	0.0651985	0.0296640	0.0239869
Average Jitter (Seconds)	0.0796475	0.0201314	0.0112332
Average Hop Count	4.04581	2.36634	2.18065

when using DTR sensor will always select the least depth available neighbor all time when the parent energy is above the energy danger threshold, so the hop count in this duration will be equal or less hop count of the default hierarchical tree path, and sensor will only select a path with longer hop count when its parent is busy or its energy becomes below energy danger which take smaller duration of the parent life time, so the overall hop count often less hop count of default hierarchical tree path.

AODV has the largest hop count because it select best available path to main coordinator regardless hop count.

We notice also that DTR keeps low end to end delay and jitter like MZBR, while delay and jitter is higher in AODV because of using longer hop count path and performing path search before transition.

1.2.2.2 Packet Delivery Ratio

The following figure shows packet delivery ratio comparison.

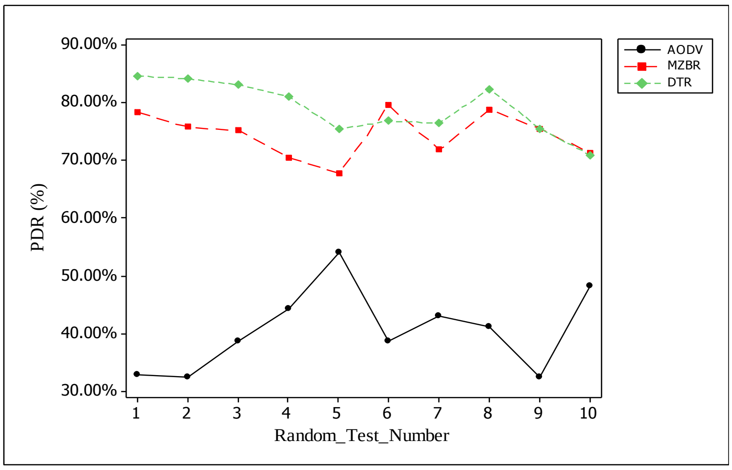

Figure (6) Packet Delivery ratio in random test

We notice that DTR offers higher average packet delivery ratio, because it can avoid busy next hop neighbors, also it can avoid bottleneck near main coordinator by using alternative available paths, whereas AODV offers the lowest one because of its broadcast control packets which may collide with beacons of other sensors, and because of the heavy work required from main coordinator and nearby sensors to replay rout request command every time AODV wants to find new path.

1.2.2.3 Reaming Energy and its Standard Deviation

The following figures (7,8) show the average remaining energy and Standard Deviation of all sensors in each random test.

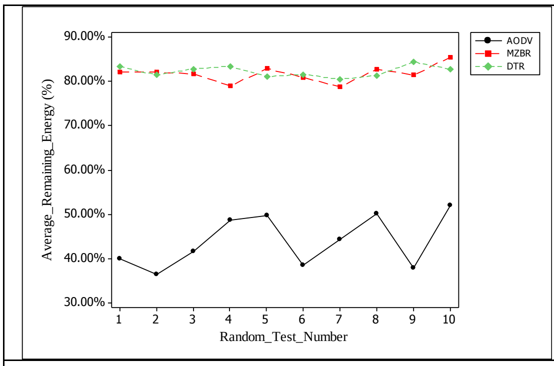

Figure (7) Average remaining energy on random test

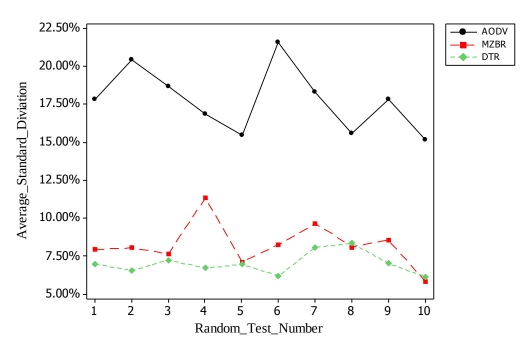

Figure (8) Standard Deviation of sensors reaming energy in random test

We notice that average energy is nearly same in DTR and MZBR, it is about 82%, but the distribution of energy consumption is different and the standard deviation of energy is less when using DTR as we will see in the figure (9).

AODV consumes more energy, and this happened because it uses a full routing path table in each sensor, and require extra control packets to maintain this table. The average reaming energy is 43.95%,

Standard Deviation helps us to notice how mush values are separated from its average value, but when one or more sensors lose its energy faster, it will not strongly affect standard deviation value, so to notice the energy distribution more clearly, we will explore the least 10% of reaming energy when using DTR,MZBR, and we will not consider AODV here because of its large SD value (17.78%).

1.2.2.4 Average remaining energy of least 10 % sensor energy

Every value in the following figure represent the average value of 10 test.

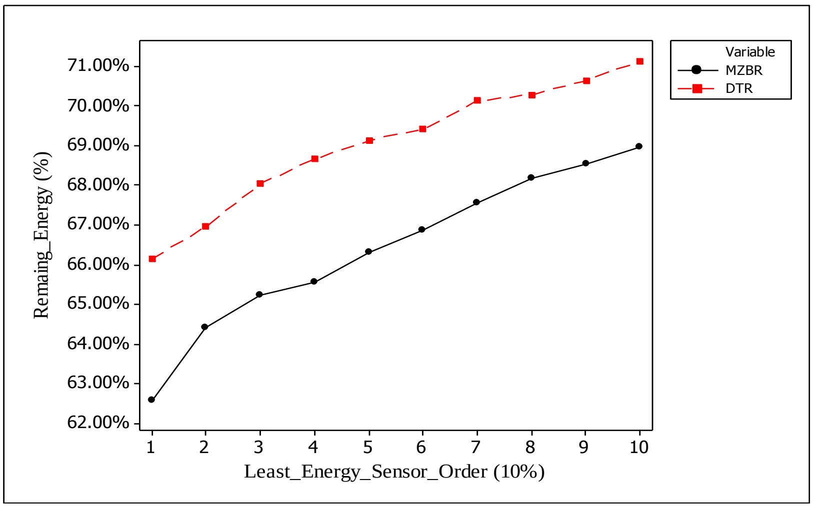

Figure (9) average Remaining energy in least 10% of sensor

we notice that DTR saves the energy of sensors from draining more quickly than others by distributing packets between many paths.

Conclusions and discussion

From our previous tests we can highlight some points:

- When sensor begins to loose parent beacons, and before the sensor decides that it actually has lost the connection with parent, there is a chance of finding another coordinator to forward packet toward it during this period when using our protocol, while in modified Zigbee Tree Routing protocol, sensor still forwarding packets to its unreachable parent until deciding that it has lost the connection and began search for another one.
- No efficient beacon scheduling is presented for IEEE82.15.4 module in NS2, so a serious degradation in network performance happens when the number of sensors which periodically send beacons increases, to overcome this limitation we adjust some of full functional device to don't transmit beacons. In case when more beacon enabled full functional devices are presented beside sending sensor with efficient beacons scheduling, this mean more available paths and more energy distribution for our routing protocol.
- Improving the parent selection procedure which construct the default hierarchical tree path for every sensor in the network, will reflect as improvement in performance of all Zigbee Tree Routing based protocols.

Conclusion

In this paper we had addressed the single hierarchical path problem in Zigbee hierarchical tree routing based protocols during many to one traffic, which causes serious energy degradation of nodes belongs to hierarchical path. Our protocol (DTR) uses many paths to rout packets hierarchically, and it dynamically switches between them according to next hop quality factor, with no extra control packets or full path routing table, and the simulation results obtained from NS2 showed better distribution of energy consumption, and improvement in network lifetime, also the configuration of protocol to select the least depth neighbor when available, and to avoid sending more packets to busy or failed neighbors are reflected in good packet delivery ratio and end to end delay compared with AODV and Modified Zigbee Tree Routing protocols.

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