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A Multi Route Knowledge based Routing Protocol for Reliable Packet Transmission in Industrial Wireless Sensor Networks

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Abstract

Wireless sensor nodes are deployed in any environments, like industrial wireless sensor networks in which they have very harsh environment, so providing reliable and congestion free efficient communication in this environment is a challenge. In this paper, we propose multi route knowledge based routing protocol which enhances link dynamics for industrial wireless sensor networks and to provide a congestion free reliable packet delivery in harsh environments. Existing reactive routing protocol has been modified to provide reliable and congestion free packet delivery along unreliable path by using local path diversity. Route discovery phase uses the congestion free path to find forwarding path, which helps in providing more efficient forwarding. Once forwarding path has been established then data packets can propagate towards destination without using location information. A reliable data delivery scheme has been introduced along with the congestion control, once the threshold of data limit or link is busy then it can use some other path or link to transmit the data to the destination in a reliable way without establishing a connection again. Our simulation results shows that this method improves packet delivery ratio, minimizes packet delay and throughput is increased in heavy traffic also.

Keywords*: WSN, AODV, AOMDV.*

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1. Introduction

Wireless Sensor Network is a collection of wireless sensor nodes deployed in any environment, which are networked together to co-ordinate among them and send the sensed data to the base station. These sensor nodes may be deployed in any environment and they may sense the data according to the area of their deployment. These wireless sensor network have lot of applications like military applications, frequency sensing, home automation, health monitoring, marine engineering to sensor under water data, Industrial applications etc. The spatially distributed sensor nodes form sensor network which monitor environmental and physical condition. The sensor node operates in small battery power; the life time of the node is months to years. Traditional communication mechanism used was wired communications, due to its cost and consumption of more resources trend shifted towards the wireless communication mechanism for data transfer. In the field of industry, traditional way of communication system is replaced by wireless sensor networks since they offer advantages of deployment in large scale, low cost of installation and maintenance [1]. These wireless sensor network used for industries were named as Industrial wireless sensor network, has lot of applications like environment monitoring, process monitoring, plant monitoring and factory automation which require reliability and delivery of packets within a time among the nodes [2].The existing routing protocols like AODV [3], AOMDV [4], and DSR [5] is not suitable for industry environment because of harsh environmental conditions, and electromagnetic interference [6]. Industrial wireless sensor networks are different from normal wireless sensor networks, due to the harsh environment, Interference between the sensor nodes they result in transmission failure, which causes delaying or missing of process or control data within deadline which is intolerable or causes huge damage in industrial applications, ultimately results in economic loss. So developing an approach which should provide a reliable and timed delivery of packets in the industrial environment became challenge. Sensor nodes are deployed in dynamic harsh environments, although we have a various reactive routing protocols, due to the dynamic nature of the industrial environment they fail to deliver the packets within time. Industrial Environment is the harsh environment where they may contain huge radiations, high temperature, very cold environment, various ultraviolet radiations emitted by various industrial equipment's, magnetic radiations by electromagnetic devices, etc may cause the improper working of the sensor devices (or) may cause the problem to communication among the nodes in the network which lead to loss of packets in the network. So reliable communication is the biggest challenging problem because of varying channel condition, and node failures that lead to topology change and connectivity problem.

2. Literature Review

The various routing algorithms used in wireless sensor networks forward their data to the intended one. These routing algorithms were initially establishes the route by the source where source routing protocols were used. Then due to the failure of the static paths because of some environmental conditions, node energy levels etc., re-establishment of path are required which consumes more time and resources. To avoid the consumption of time and resources to reestablish a path from source to the intended one, reactive routing protocols were introduced. There are several reactive routing protocols like AODV, AOMDV and DSR to function on wireless sensor networks. AODV [3] is AdhocOndemand Distance Vector routing protocol which is a reactive routing protocol which do not keep any routing information, nor participate in any periodic routing table exchanges. AODV protocol broadcast the route discovery packets only when it is necessary and from the position from where it is required. AOMDV [4] is a AdhocOndemand Multipath Distance Vector Routing protocol which is extension to single path routing protocol known as AdhocOndemand Distance Vector routing protocol. During route failures this protocol efficiently find alternate path, fast recovery is possible in dynamic networks. It computes multiple paths during route discovery process and is mainly developed for high dynamic adhoc networks where link failures and route break occur frequently. Route discovery for every link failure is required in AODV, which consumes more time and resources. As in AODV it uses single route request (RREQ) but finds multiple paths by accepting many or duplicate RREQ packets. DSR [5] Dynamic Source Routing is a reactive routing protocol which uses the cache in every node to maintain the path from other nodes to the source node. Whenever the path failure occurs while transmitting the data, then the nodes should update the path to the source node by using path establishment mechanism. An efficient route selection algorithm was designed for industrial wireless sensor network [6] and its aim was to provide reliability and energy efficiency in the network. It considers the link weight, forwarder energy, and traffic congestion and interference level to select a path to transmit the data to the destination. Next hop node is selected based on the node having high link weight and more forwarder energy to transmit it to the next forwarder node in the network. Data from the environment may be different types hence sensor nodes must be capable of transmitting various data including multimedia data. Lot of algorithms is proposed on multimedia wireless sensor networks [7] to route the data by considering various QOS parameters. Main objective of this type of algorithms is to prioritize the sensed data based on request conditions and to allocate the certain level of quality of service. The opportunistic routing [OR] [8] has been proposed as a solution to overcome the problem of unreliable transmissions and more energy consumptions, which provides the improvement in robustness and consumes less energy compared to traditional transmissions to deliver the packet to the intended one. The data in the wireless sensor network is broadcasted among the nodes, opportunistic routing takes the advantage of this broadcast feature to utilize the local neighbors of the any sensor node or forwarder node in the forwarding mechanism. Each sensor node has multiple neighbors and these neighbors can here the data transmission happening among the one hop neighbors through wireless communication. In this opportunistic routing instead of relying on the single sensor node to forward the packet, it selects the multiple nodes which can overhear the forwarding candidate. Although opportunistic routing has been used to provide the reliability in packet delivery, it did not concentrate on preserving the energy to a maximum extent. EXOR [10] is also an opportunistic routing but considers expected transmission count [ETX] as a metric for routing the packets. This protocol was provided with an intension of achieving sent percent reliability over unreliable paths with minimum number of transmissions. When the source node has the data to send it to the destination, it broadcasts to its neighbors, subset of nodes can hear that data. Broadcasted packets consist of forwarder list based on the priorities and highest priority node will take the forwarding action. Energy consumption by the sensor node due to these reasons sensing the data, receiving data, forwarding data and processing data. The node may also act as router while transmitting other nodes data in the network, which consumes the energy. So to utilize the available resources in the network cluster concept came in to existence [11]. If the sensor network consists of more number of sensor nodes, these nodes can be grouped into small number of clusters. Each cluster consists of some nodes and a cluster head to represent the cluster. This cluster head is also responsible to coordinate the sensor nodes in the cluster. The cluster formation is necessary because it may increase the lifetime of the nodes which in turn sensor network. Cluster based load balancing is used in many application areas of wireless sensor networks, cluster members are grouped in to the clusters based on the maximum transmission power and communication cost. But in this approach if any of the cluster head fails then there is no recovery for this approach [13].

3. System Model

We have considered a multi hop WSN and nodes are closely positioned, each node in the networks has more number of neighbors. When a node has a date to the destination, the on-demand route discovery process is started, if there is no recent path to the destination. When nodes are installed in wireless sensor networks they must start checking their transmission range and nodes which comes under their transmission range. Once the transmission range check process has been completed, each node knows its transmission range and neighbor nodes. Fig. 1 describes the overall architecture of multi route knowledge based routing protocols. This approach is a cross layer design between MAC and routing layers to increase the resilience to the dynamics of the link. Entire design of our work is divided into five tasks.

a) Reliable route discovery
b) Selecting supporters
c) Forwarding decision and prioritizing
d) Congestion control
e) Packet transmission

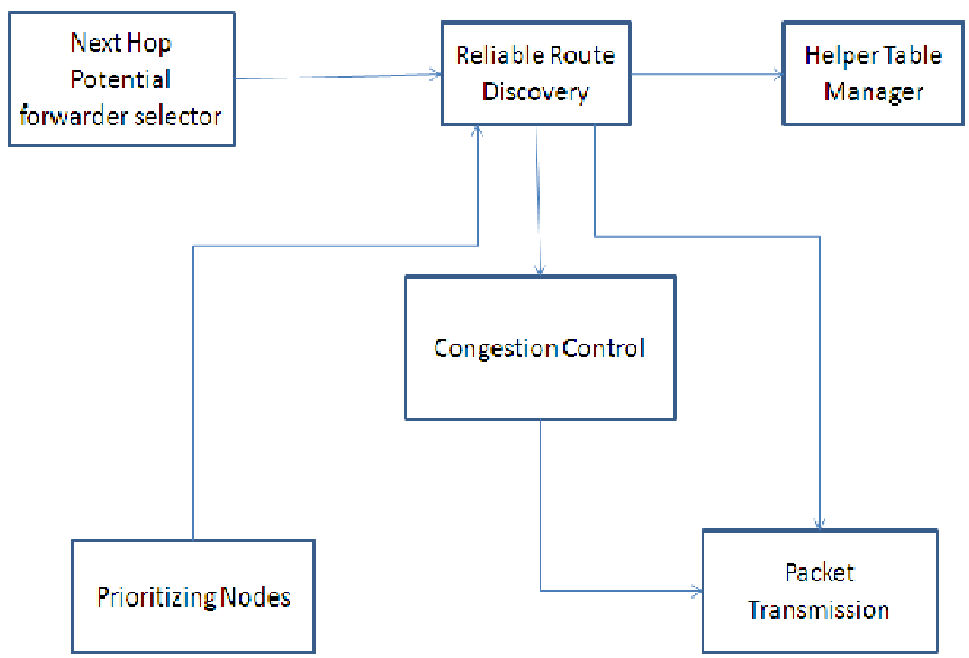

Fig. 1: Architecture of multi route knowledge based routing protocol

a) Reliable Route Discovery

Each sensor node in a wireless sensor network must find the path to the sink or the destination before transmitting data packets. This path must be reliable and efficient to deliver the packets to the destination. In this phase, source simply broadcast route request RREQ packets till it reaches destination. Once it reaches the destination it will send a reply to this request packet along the same path or may be at different paths. Reliable route discovery process consists of mainly two sub modules.

i. Route Request (RREQ) process
ii. Route Reply (RREP) process

Route Request (RREQ) Process

This is the first and common process to be carried out by any node that has the data to be sent to the base station. When there are several nodes deployed in industrial environments, some node X senses some data in the environment. This sensed data from that node has to be sent to the destination by estimating a path between them. To initiate a route establishment from the node which has sensed the data and node which is intended one, it needs to broadcast the route request packet (RREQ) to the nearest neighbors. Each RREQ packet consists of requester node identifier, destination to be reached, sequence number and nodes travelled so far. Congestion free scheme can be introduced to avoid the multiple broadcasting of packets at current forwarding node. Node which is given the higher priority will forward the packet and rest will wait their time to be expired. If congestion free timer expires and if they did not get any of acknowledgements then next priority node will take the task of broadcasting RREQ. Intension of using this operation is to amplify the delays of RREQ packets across different paths. This operation enables the Route Request packet (RREQ) to travel faster along the preferred path using certain metric.

To consider the congestion free delay of any forwarding node V_j which is denoted by t_{ij}, which receives an RREQ from V_i.t_{ij} can be defined as

t_{ij}=(((hopcount)/($\sum P_{ik}P_{kj}$+1))+ ((max energy/available energy$_j$)/ No. of CN$_j$) .t[V_k€S(i,j) -→1]

Where t→time slot, CN$_j$→ Common neighbors of node j.

Hopcount→ number of nodes traversed by RREQ from source node so far.

P_{ik} is the packet delivery ratio of node k from node i.

Max energy is the maximum energy in joules allocated to the node when it is deployed; available energy is the amount of energy in joules left in the particular node.

The above fig. 2 illustrates congestion free scheme. Congestion free scheme will be calculated by any node which receives RREQ considering or assuming itself as guide node and considering previous hop node as upstream guide node. For example from source S in the above figure nodes 1, 2, 3, 4, 5 receive a RREQ packet, when node 3 calculates it's congestion free delay

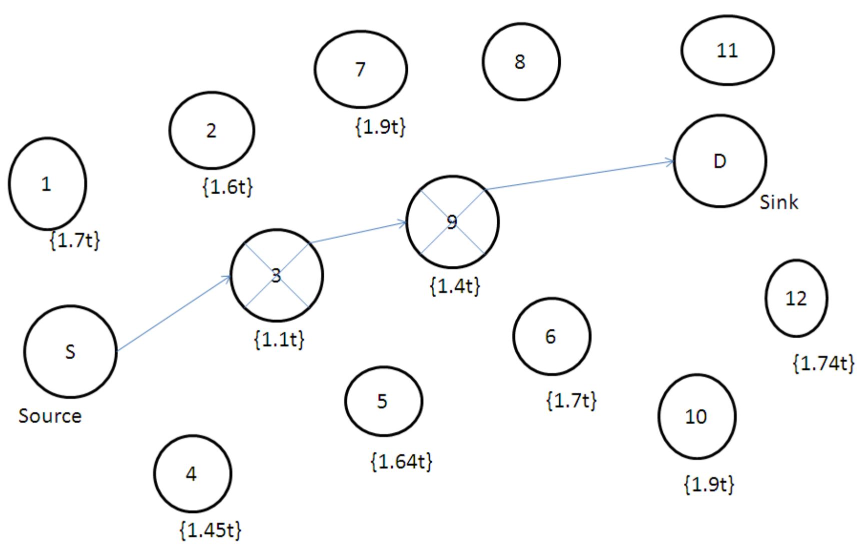

Fig. 2: Example of forwarding RREQ packet along with congestion free delay

it considers itself as guide node and S as the upstream guide node. Each node will be having neighbor tables, from those neighbor tables 1, 2, 4 and 5 will be identified by 3 as mutual nodes, then it can calculate congestion free delay. In above figure {1.7t} beside the supporting node 1 indicates that congestion free delay or time it has to wait. At node 3 packet recipient ratio or congestion free delay is 1.11t according to formula 1. Comparison is made on 3 nodes which are 1, 2, 3, 4 and 5, 3 has less congestion free delay with respect to nodes 1, 2, 4 and 5. 3's timer expires first compared to other nodes hence 3 broad casts RREQ and has higher priority to forward the RREQ. Similarly node 9 forwards the packet before other nodes in next hop, hence RREQ traverses along the path Source→3→9→sink. Once it reaches sink it notifies the source about path. From the above declared equation we can say that higher priority is possibly given to path with more potential helpers or supporters and supporters with their high energy level. Route reply packet is sent back to source node by sink node along the reverse path where the route request packet has been travelled. Duplicate RREQ packets will be discarded, only RREQ which receives first will be considered and replied to it by sink.

Route Reply (RREP) Process

Once the route request reaches the destination then the node has to reply to the source node by using route reply packets. When route reply is sent by destination, the node which is intended receives it, checks weather it is selected next hop. If it is the intended next hop or node along the path to the destination, then it makes itself as guide node. Then this particular guide node records it's upstream guide node id for the current RREP and forwards it. This forwarding process continues until the route reply reaches the source node along the reverse path in which route request packet has been travelled. Once the route reply packet reaches the source along the guide nodes hence that path becomes the guide path to the destination from source for transmitting data packets.

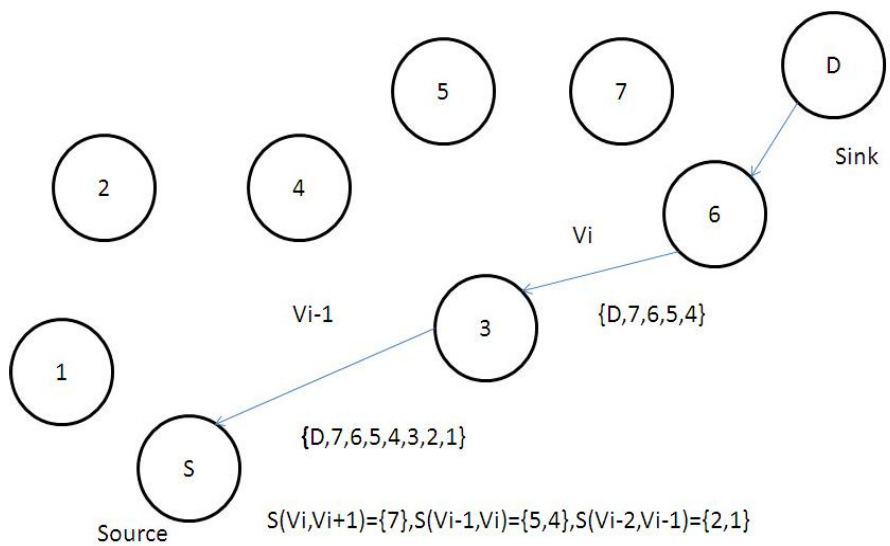

Fig. 3: Example of RREP propagation

The above fig. 3 is an example of RREP propagation corresponding to previous route request phase. Suppose 6 is current forwarding guide node, 3 is the upstream guide node and it's supporting node is S(6,D) will be attached in the RREP. When the guide node 6 forwards the data to next guide node 3 for example support node 4 over hears this RREP and records the piggy backed information {D,7,6,5,4}. 4's one hop neighbor set N(4) is {2,3,4,5,6}. Therefore potential forwarding candidates are N(4) intersection {D,7,6,5,4} ={7,6,5} towards destination.

b) Selecting supporters

Before sending the RREP packet by the sequence of nodes from the destination to source, they send the added information of one hop common neighbors which we call it as supporter nodes. Selecting the supporters among the available is necessary because to avoid unnecessary delay in identifying the routes again from the point of failure. Selecting supporters among the available depends on its allocated priority at prioritization phase. Once the failure of the guide node occur then higher priority supporter will be selected as guide node to transmit the data without reestablishing a path once again. This phase adds as an extra advantage to avoid the collision during the data transmission phase.

c) Forwarding Decision and Prioritization

This is the run time module which selects the next hop potential forwarders and assigns the priorities to them. Node which is forwarding the data is assumed as V_i , it has the many upstream nodes one of which need be selected as actual forwarders based on the packet recipient ratio and energy of the nodes. Suppose node V_{j+1} is the upstream node which is assigned a higher priority based on PRR and node energy then it will be taken as a guide node or actual forwarder node. The upstream nodes whose priority stands next to actual forwarder must be grouped according to priority and tailed to the packet, which must be forwarded to the actual forwarder of upstream.

This tailing of the prioritized node details help in finding alternate forwarder in case of actual forwarder failure or link failure. When the data packet is received by the node it checks weather it is the intended receiver. The process of checking is done by forwarding decision module. If yes or it is the intended receiver then it caches the incoming packets and starts the congestion free timer to return the ACK message to the sender. The timer value is given based on ranking in the intended receiver list. Suppose let us assume that if there is no forwarder candidate list with higher priority or no candidate forward the ACK, then the node broad casts the ACK to upstream node then any of the node in that can take forwarding task based on their back off timer to transmit ACK to the sender.

d) Congestion Control

After route establishment phase is completed there exist multiple paths to the destination. Guide path is the one which takes the data packets from source node to the destination. Suppose the limit of data that is traversed in that guide path exceeds then it may drop the packets. So to avoid dropping of the packets, if the guide path is busy then packets are transmitted to destination using supporting nodes which are identified at the route discovery process only. If another node has data to send to the same destination or sink node in the network then it cannot follow the same guide path, since many nodes cannot transmit more data at a time which may result in congestion or dropping of the packets. So to avoid this dropping of the packets it may take another path by using the local information of nodes. Another path is used based on support node set of the guide nodes along the guide path. If that path is used then packets will reach destination at any cost from another path without fail, that algorithm is explained below.

1. Procedure: Void Congestion control (packet *p)
2. If node has data to send
3. Then Broad cast the RREQ
4. Calculate the congestion free delay
5. Forward the RREQ until it reach the destination
6. //Using least congestion free delay node as actual broadcaster

7. Reply with RREP packet from destination node to previous node
8. Select the guide node allocate the priority to support node and send it with RREP packet
9. //till it reach source node, priority is based on PRR and Energy of particular node
10. Send data packet along preferred path
11. While (path from source to sink)do
12. If no data on guide path then
13. Send packet //use guide path
14. If at each node data is not ACK then
15. Find alternative path then
16. Use nearest alternative path
17. // path may be from support nodes which are present around range of guide nodes
18. If ACK
19. End
20. Else any alternative path
21. Else start establishing path
22. Else end
23. Else Check any alternative path
24. End

e) Packet Transmission

Co-operation among the nodes in wireless sensor network is required, since all the nodes are not directly in the range of sink. Hence nodes in wireless sensor network must co-operate among themselves to ensure that nodes are communicating with other node in the network. Entire procedure of this approach how it helps in co-operative forwarding is described here. The node which has data packets broadcasts it to all the nodes including set of forwarding candidates and their priorities. These assigned priorities are followed by all the candidates to forward the packet. Each node or prioritized node in the list having received the packet correctly will start congestion free timer, this timer value depends on assigned priority of that node. Node with higher priority will have the lower timer value. Node which has taken forwarding task or whose timer expires will reply with ACK, to inform the sender and other nodes competing to send the packets. Then that node rebroadcasts the data packets towards the downstream link. If there is no forwarding candidate is available towards the downstream to receive the packet, then sender node enables retransmission mechanism. Congestion free timer value of k'th node in the network is denoted by t(k). Higher priority nodes will have less timer value and lower priority nodes has to wait until it confirms that no higher priority node has relayed, forwarded the packet. Hence lower priority node has higher t(k) value or it is an function increasing with k. The protocol we are going to use at link layer to measure the collision and to avoid it is CSMA/CAMAC. So t(k) can be defined as

$t(k)= (T_{SIFS} + T_{ACK}).K$

$T_{SIFS} \rightarrow$ Short inter frame space

$T_{ACK} \rightarrow$ Delay for sending ACK.

4. Results

This work is implemented and demonstrated in network simulator 2, which is combined with the existing reactive routing protocol AODV and compared results with other reactive routing protocols. There are lots of metrics to measure the efficient working of any reactive routing protocol.

a. Comparison Baselines

Here there are some reactive routing protocols to compare the approach, brief description about these are:

- AODV-ETX[3]: It is also an extension of AODV protocol which uses least ETX [expected transmission count] to find a path from source to destination at route discovery phase. In this retransmission of the packets are allowed, i.e. maximum 3 retransmissions by any hop in the network is sanctioned at link layer. Since other protocols do not adopt this retransmission mechanism.
- REPF[27]: Reliable efficient packet forwarding is modeled with the intension of improving the performance of AODV by utilizing the local path diversity. During the route discovery phase it identifies the best path along with the alternative path of same cost by using ETX function. It doesn't utilize the path diversity provided by the nodes in the network.

b. Simulation Setup

NS2 is the network simulator which is used here to implement and simulate the results. Density of the nodes is the maximum number of nodes deployed in a given 200m X 200m square area. The deployment of the nodes in any sensor environment is done randomly without any pre specified metrics. The transmission range for each node is set as a radius of 50m. The destination node is placed at the bottom of the sensor area (0m,0m) and the source node is placed at the top of the sensor area (200m,200m). The parameter used T is set to 0.005s in my approach. Each route reply packet is not acknowledged by the guide nodes in order to avoid the collision. Route reply is acknowledged directly by the receiver, not by each one hop nodes. The performance metrics are:

1. Packet delivery ratio: It is the total number of packets received to the total number of packets sent.
2. End to End delay: Time taken by the node to send a packet from source node to sink node.
3. Data transmission cost: Total number of data transmissions required to transmit the data from source to destination.
4. Control message cost: Total number of control messages transmitted from source to destination for transmitting single packet from source to sink.

c. Performance Analysis

Performances of different protocols are evaluated against different node densities and results are shown in figure, node densities are varied from 50 to 200. Fig. 4 indicates the packet delivery ratio of different routing protocols under different node densities. Packet delivery ratio is considered for end to end to packet transmission, Multi route knowledge based routing protocol achieves very high packet delivery ratio with increasing node density and having maximum number of nearest neighbors closer to the destination. In

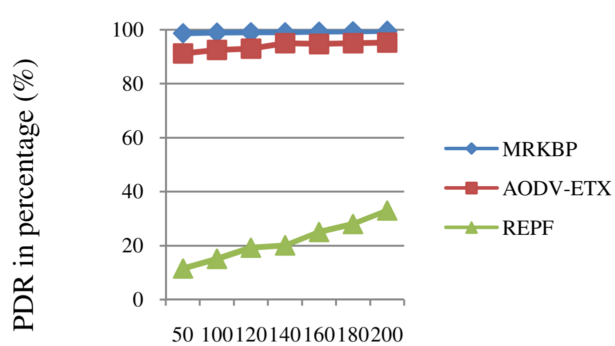

Fig. 4: Comparison of packet delivery ratio versus node density

AODV_ETX best path is identified based on ETX metric, rather than using hop-count metric [3]. At each hop in AODV_ETX three retransmissions of the packets are allowed in link layer, which intern helps in achieving the packet delivery ratio high as shown above. Since the node cooperation is restricted to limited scope in REPF it achieves less packet delivery ratio which is around 30% as shown above. Multi route knowledge based routing protocol achieves 98% packet delivery ratio and increases with node density as shown, which also enables the MAC layer packet retransmissions.

Fig. 5 describes the performance comparison of end to end delay against node density. Since AODV-ETX has more delay comparatively because delay or time consumed for retransmitting a packet is much larger than time taken for cooperative forwarding. AODV-ETX takes several retransmissions to transmit the packet hence end to end delay comparatively higher. End to end delay of REPF and MRKBP is relatively closer since REPF doesn't allow maximum retransmissions and in MRKBP retransmission is done with available knowledge at MAC layer hence it's delay is less compared to AODV-ETX as shown above.

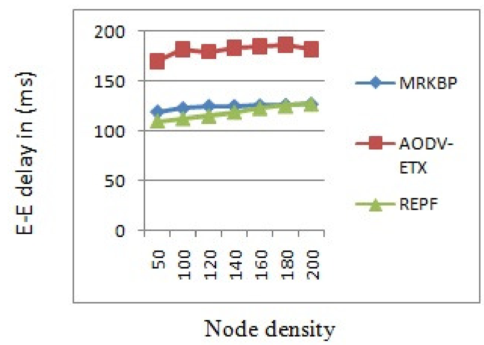

Fig.5. Comparison of end to end delay versus node density.

Fig. 6 shows the data transmission costs against different node densities for successful end to end packet transmissions. MRKBP has data transmission cost slightly higher than REPF, since AODV-ETX has higher data transmission cost because of higher retransmissions carried out while transmitting a packet which is as shown above. Fig. 7 describes comparison of control message cost against node densities. The control message cost of MRKBP is slightly equal to REPF since retransmitting packets doesn't require control messages to be transmitted, since path is identified at the beginning of the route establishment phase. AODV-ETX has higher control message cost compared to other two routing protocols as shown above.

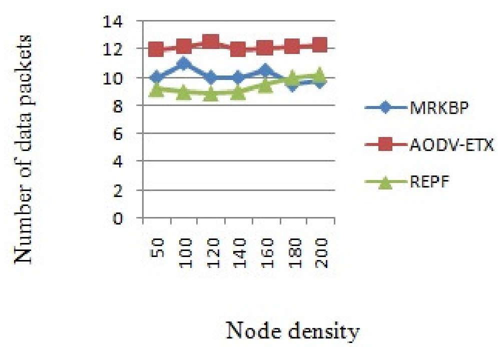

Fig. 6: Comparison of data transmission cost versus node density

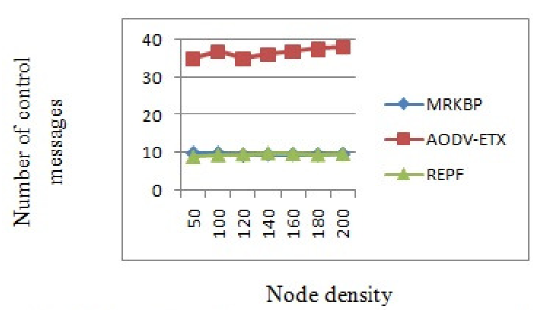

Fig.7. Comparison of control message cost versus node density.

5. Conclusion

Designed multi route knowledge based routing protocol which can be used with most of the existing reactive routing protocols in wireless sensor networks/ Industrial wireless sensor networks to increase the packet delivery ratio, energy efficiency and to provide reliability in packet transmission over unreliable paths. Congestion free scheme has been introduced to find the best or robust virtual path in route discovery process with lower overhead. In this approach without bothering about the location information data packets can be transmitted towards the destination by using the virtual path. So by this we can conclude that our approach can be effectively used with any of the existing reactive routing protocol to increase the packet delivery ratio over the other and energy efficiency in turn increases the network lifetime. End to end delay seems to be same as the previous reactive routing protocols. Simulation results are shown and compared with other reactive routing protocols, which shows the improvement in robustness, end to end energy efficiency and latency.

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