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RER: Reactive Efficient Routing For Wireless Sensor Networks

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Abstract:** In Wireless Sensor Networks (WSNs) the major challenge is to provide efficient and reliable communication between source and destination, especially in industrial WSNs (IWSNs) with dynamic and harsh environments. Hence, a Reactive Efficient Routing (RER) is designed to improve the routing protocol to provide efficient packet delivery against the unreliable wireless links. Here Dynamic Source Routing (DSR) protocol is used in the proposed system and a special technique called biased back-off scheme used to find a robust guide path through which cooperative forwarding opportunities are more. So, the data packets are sent to the destination efficiently. Performance of RER is measured using four parameters Bit error rate, Packet delivery ratio, Throughput and Control overhead packet through simulation.

***Keywords:** Wireless Sensor Networks; Route Request; Biased Backoff scheme; RouteReply; Cooperative Forwarding; Unreliable Links;*

I. INTRODUCTION

Wireless sensor networks (WSN), sometimes called wireless sensor and actuator networks (WSAN), are distributed sensor to handle environmental or physical conditions like temperature, sound, pressure and to cooperatively pass the data destination through network. Wireless sensor networks are developing mainly to improve military applications. Such WSNs are used for many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

II. MODULES

Module 1: **Route Request (RREQ) Propagation** is used to find guide path for transferring data packets between source and destination by flooding an RREQ message.

Module 2: **Biased Backoff Scheme** amplifies differences of RREQ's traversing delays along different paths intentionally. This module helps the RREQ to travel faster along the preferred path which is introduced at the current RREQ forwarding node.

Module 3: **Route Reply (RREP) Propagation** with the help of guide node traverses the guide from source to the destination.

Module 4: **Cooperative forwarding** with the list of forwarding candidates and their priorities, data packets are broadcasted from source node. While sending the packet if any links between any guide nodes in the guide path is lost, cooperative forwarding technique is used to find another path.

III.FUNCTIONAL ARCHITECTURE OVERVIEW OF RER

Figure 1 shows the architecture overview of RER, which is a middle-ware design across the MAC and the network layers to increase the resilience to link dynamics for WSNs/IWSNs.

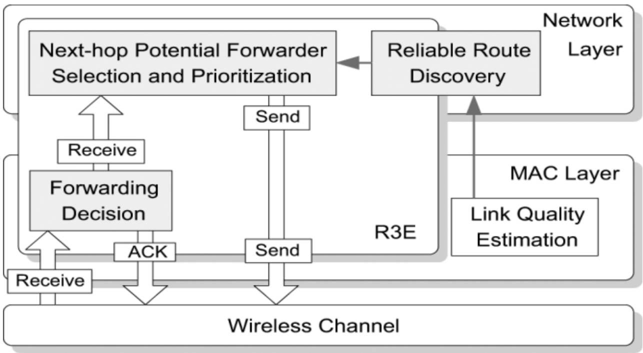

Fig. 1 Functional architecture overview of RER

The RER enhancement layer comprises of three main modules:

- The reliable route discovery module
- The potential forwarder selection and prioritization module
- The forwarding decision module.

The route information for each node is found and maintained by the reliable route discovery module. During the route discovery phase, each node involved in the cooperative forwarding process stores the downstream neighbourhood information, that is, when a node serves as a forwarder, it already knows the next-hop forwarding candidates along the discovered path.

The other two modules are responsible for the runtime forwarding phase. When a node receives a data packet, the forwarding decision module checks whether it is one of the intended receivers.

- If yes, this node will cache the incoming packet and start a backoff timer to return an ACK message, where the timer value is related with its priority in the forwarding candidate list.
- If there is no other forwarder candidate with higher priority transmitting an ACK before its backoff timer expires, it will broadcast an ACK and deliver the packet to the upper layer, i.e., trigger a receiving event in the network layer.

Then, the potential forwarder selection and prioritization module attaches the ordered forwarder list in the data packet header for the next hop. Finally, the outgoing packet will be submitted to the MAC layer and forwarded towards the destination.

VI.RELIABLE GUIDE PATH DISCOVERY

1. ROUTEREQUEST (RREQ) PROPAGATION

While sending data packet from source to destination RREQ message is flooded. When non-duplicate RREQ is received, upstream node id and RREQ sequence number is stored in the intermediate nodes for reverse routing. Because of this effective scheme, along the preferred path the RREQ travels faster.

Let,

v_i - last-hop node of an RREQ
v_j - current forwarding node of an RREQ (v[j])
$N(i)$- the set of v_i's one-hop neighbors
$CN(i,j)$- the common neighbor set between $v_i$and v_j
v_k– helper between $v_i$and v_j as the common neighbor of $v_i$and v_j
P_{ik}, P_{ij}, P_{kj} and P_{ij}- Packet Reception Ratio (PRR) between $v_i$and v_j
$H(i,j)$ - the set of helpers between $v_i$and v_j
t_{ij} - the backoff delay at the current forwarding node v_j, which receives an RREQ from v_i
t_{ij} is calculated using the formula

$$t_{ij} = \frac{HopCount}{\sum_k P_{ik}P_{kj}+1} \cdot \tau, v_k \in H(i,j) \qquad \ldots(1)$$

τ - time slot unit
HopCount- RREQ's hop distance from the source node.

Biased backoff scheme is illustrated in the figure 2. Every node assuming itself as a guide node and lost hop node as upstream guide node which is forwarding the RREQ, the backoff delay is calculated.

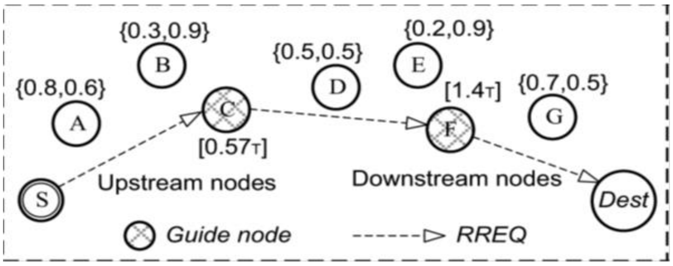

Figure. 2 Example illustrating the biased backoff scheme

In the example shown above from the source S nodes A, B, and C receive an RREQ. C, it considers itself as a guide node and S as the upstream guide node. C knows that A and B are helper nodes with the help of local neighbouring table. Then, backoff delay is calculated by C. Compared with A and B, C has a shorter backoff delay. When C's backoff timer first expires, the RREQ is rebroadcasted and so C has a higher priority to forward the RREQ. Similarly, node F forwards the RREQ before D and E. Thus, the RREQ that travels along the path [S→C→F] arrive at the Dest first. Algorithm 1 describes how a node handles a received RREQ.

Algorithm 1: How a node v[j] handles the RREQ received from node v[i]

```
int recvRREQ(packet *p) {
        if(non duplicate RREQ)
        {
        if(v[j]==D)
        {
                return RREP;
        }
        else
        {
                if(i==j)
                {
                        CN[i][j]=N[i]∩N[j];
                }
                /* get common neighbour set CN[i][j], v[k] belongs CN[i][j] and sort according PRR ratios with respect to k */
                H[i][j]=CN[0][0];
                CN[i][j]=CN[i][j]-CN[0][0]; // CN[0][0] is always the first element of CN[i][j]
                do{
                        if(checkconnectivity(H[i][j], CN[0][0]))
                        {
                                // CN[0][0] is within the transmission range of any node in H[i][j]
                        H[i][j]= H[i][j] ∪ CN[0][0];
                        }
                        CN[i][j]=CN[i][j]-CN[0][0];
                }while(CN[i][j]!=0);
        }
        backoff(T, p);
                if(t>T)
                {
                        forwarderRREQ(p);
                }
        }
        Else
                Drop p;
}
```

2. ROUTEREPLY (RREP) PROPAGATION

The node receives RREP from destination node or intermediate nodes, it checks whether the selected next-hop of the RREP. If yes the node itself marks as a guide node and records its upstream guide node id and forwards it until it reaches the source node via the RREQ message propagated, finally the guided path is obtained from source to destination for forwarding the data packets. In the proposed system Route Reply (RREP) propagation implements the forward path setup and also notifies the potential helpers to perform the cooperative forwarding.

Algorithm 2: How a node v[j] handles the RREP received from its downstream guide node v[i]

```
void recvRREP(packet *p){
        if(non duplicate RREP)
        {
                if(v[j]==v[i-1])
                {
                        G=v[i-1];
                        // G - guide node when v[j] is next hop node and v[i-1] is guide node
                        record v[i];
                        record H[i-1][i];
                        // get RREP's next hop node v[i-2]
                        //attach v[i], H[i-1][i], v[i-1] and H[i-2][i-1] to RREP
                        /* v[i-2] is v[i-1]'s upstream guide node; the helper set is ordered descendingly by the PRR toward the
                        downstream guide node */
                }
                else if(v[j] H[i-1][j])
                {
                        record v[i+1];
                        record H[i][i+1];
                        record v[i];
                        record H[i-1][i];
                        Drop p;
                }
                else
                        Drop p;
        }
        else
                Drop p;
}
```

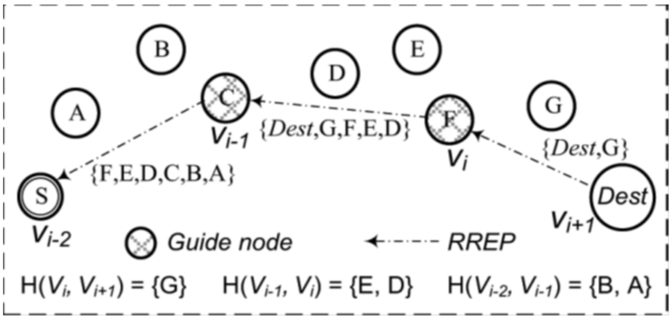

Figure 4. An example illustrating the RREP propagation

With respect to Figure 3, RREP propagation is illustrated in Figure 4. If *F* is the guide node currently forwarding RREP, *C* is *F*'s upstream guide node, helper set *H(C, F)* and *H(F, Dest)* are attached in the RREP. When the guide node F forwards the RREP to its upstream guide node *C*, helper *D* overhears this RREP and records the information *{Dest,G,F,E,D}*. *D*'s one-hop neighbor set *N(D)* is *{B,C,E,F,G}*. Therefore, its potential forwarding candidates when forwarding data packets toward the Dest would be $N(D) \cap \{Dest,G,F,E,D\} = \{G,F,E\}$. Especially in harsh IWSNs, we consider the possibilities of RREQ and RREP transmission failures because the wireless links are unreliable. Since there exist multiple paths between the source and the destination, RER is fault-tolerant to the failure of RREQ. However, the transmission reliability of RREP is desirable to be guaranteed, since the RREP returned by the destination node may collide with RREQs in the network. Another route discovery process should be launched by source node if an RREP is lost, which will result in a long routing discovery delay.

3. COOPERATIVE FORWARDING

The description of cooperative forwarding technique in RER is as follows. The source node floods a data packet, which has the list of forwarding candidates (helper nodes and the downstream guide node) and their priorities. To relay packet, assigned priorities are followed by those candidates. Each candidate will start a timer whose value depends on its priority if it has received the data packet correctly. Shorter is the timer value, the priority is higher. Sender is notified with an acknowledgement and to suppress other contenders when the candidate expires its timer. Then, data packet is rebroadcasted toward its downstream link. If the retransmission mechanism is enabled, the sender will retransmit the packet when no forwarding candidate has successfully received the packet.

$t(k)$ is denoted as the backoff timer value of the k^{th} candidate. $t(k)$ is an increasing function of k. Suppose the link layer protocol is based on CSMA/CAMAC, $t(k)$ can be defined as

$$t(k) = (T_{\mathrm{SIFS}} + T_{\mathrm{ACK}}) \cdot k \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where T_{SIFS} is the value of Short Inter Frame Space, T_{ACK} is the transmission delay for sending an acknowledgement.

$T_{omd}(k)$ is denoted as the one-hop medium delay of the k^{th} candidate, which is the time interval between a data packet broadcasted by the sender and the k^{th} candidate claiming that it has received the packet. It is defined as

$$T_{\mathrm{omd}}(k) = T_{\mathrm{DIFS}} + T_{\mathrm{DATA}} + (T_{\mathrm{SIFS}} + T_{\mathrm{ACK}}) \cdot k \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where T_{DIFS} is the value of Distributed Inter frame Space (DIFS), T_{DATA} is the transmission delay of data packet, and the signal propagation delay is ignored. For sender v_i, given n sequential forwarding candidates ($j_1 > j_2 > \cdots > j_n$), we have the expected one-hop media delay $E_{omd}(i)$

$$E_{\mathrm{omd}}(i) = \sum_{k=1}^{n} \{T_{\mathrm{omd}}(k) P_{ijk} \prod_{m=0}^{k-1} \bar{P}_{ijm}\} + T_{\mathrm{omd}}(n) \prod_{m=1}^{n} \bar{P}_{ijm} \qquad \ldots\ldots\ldots\ldots(4)$$

where $\bar{P}_{ijm} = 1 - P_{ijm}$ and $\bar{P}_{ij0} = 1$.

In wireless networks, with a higher PRR toward the downstream guide node, a potential forwarder possibly has a shorter distance from that guide node. As longer distances result in lower received signal strength and hence increases probability of packet loss. So, the relay priority rule is. When a guide node transmits the data packet, the downstream guide node has the highest priority; and according to their PRRs toward v_i, the helper nodes *H(i-1,i)* are ordered descendingly. When the downstream guide node fails to receive the packet, while a helper v_j *in H(i-1,i)* receives the packet and takes the forwarding task. The forwarding candidates of v_j are given by $N(j) \cap DNS(j)$. The forwarding candidate set of is composed of three parts: 1) the helper nodes who have higher priorities than v_j in *H(i-1,i)*; 2) the downstream guide node ; and 3) $N(j) \cap (H(i,i+1) \cup \{ v_{i+1}\})$. To achieve the minimum number of transmissions, the relay priorities are ordered as: Priority of 3) Priority of 2) Priority of 1).

VII. RESULTS

1. BIT ERROR RATE

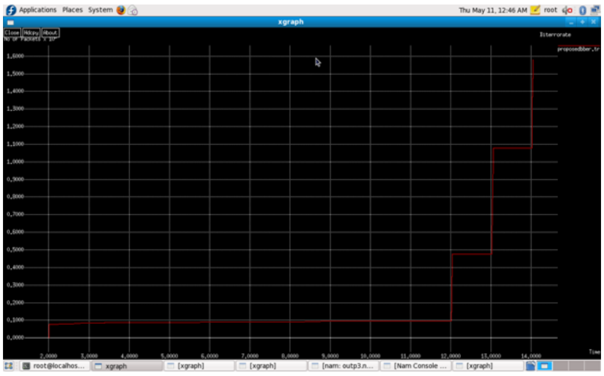

Figure 5 Bit Error Rate

The bit error rate is the number of bit errors per unit time. The above graph shows the Bit error rate of nodes. The graph shown in the figure 5, time is along x-axis and number of nodes is along y-axis. The variations in the graph are shown in the table

1. Table 1 Bit Error Rate

Time(s)	2.00	3.22	12.01	13.02	14.01
No. of Packets*10^3	1	85	96	476	1079

2. THROUGHPUT

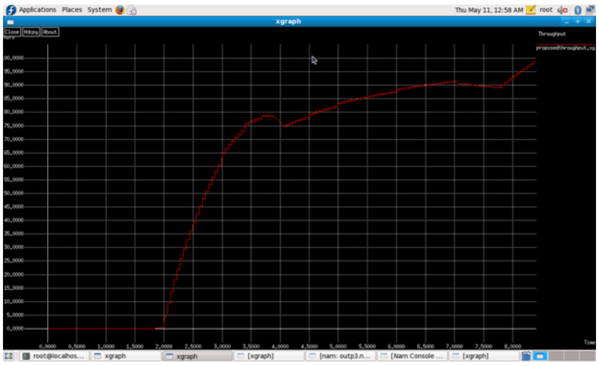

Figure 6 Throughput

In data transmission, network throughput is the amount of data moved successfully from one place to another in the given period and typically measured in kb/s. The above graph shows the Throughput. The graph shown in the figure 6, time is along x-axis and KB/s is along y-axis. The variations in the graph are shown in the table 2.

Table 2 Throughput

Time(s)	0.015	2.50	3.00	4.50	7.10
KB/s	0.00	39.19	63.33	78.44	90.42

3. PACKET DELIVERY RATIO

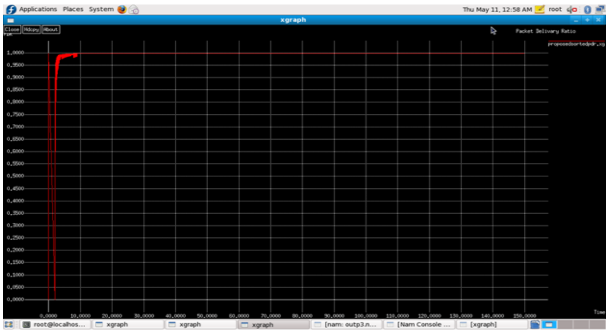

Figure 7 Packet deliver ratio

The ratio of packets that are successfully delivered to a destination compared to the number of packets that have been sent by the source. The above graph shows Packet Delivery Ratio of nodes. The graph shown in the figure 7, time is along x-axis and number of nodes is along y-axis. The variations in the graph are shown in the table 3.

Table 3 Packet Delivery Ratio

Time(s)	0.00	0.00	0.00	70.96	149.82
PDR	0.00	0.20	0.60	0.99	0.99

4. CONTROL OVERHEAD PACKETS

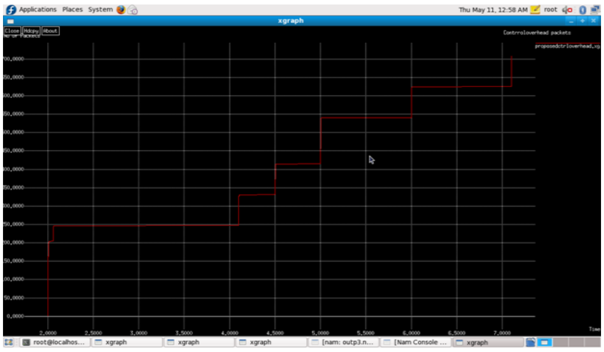

Figure 8 Control overhead packet

It reduces the overall overhead of the packets. The above graph shows the Control overhead packets. The graph shown in the figure 8, time is along x-axis and number of nodes is along y-axis. The variations in the graph are shown in the table4.

Table 4 Control overhead packets

Time(s)	2.00	4.10	5.00	6.00	7.10
No. of Packets	1	247	415	441	625

CONCLUSIONS

The presented RER can augment most existing reactive routing protocols in WSNs/IWSNs to provide reliable and energy-efficient packet delivery against the unreliable wireless links. In the route discovery phase to find a robust virtual path with low overhead a biased backoff scheme is introduced. Without utilizing the location information, data packets can still be greedily progressed toward the destination along the virtual path. Therefore, RER provides very close routing performance to the geographic opportunistic routing protocol. To demonstrate the effectiveness and feasibility of DSR an extension is provided to DSR with RER. Simulation results showed that, DSR-RER can effectively improve packet delivery ratio with low overhead and high throughput.

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