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LR^3: Link Reliable Reactive Routing Protocol for Wireless Sensor Networks

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ABSTRACT

Existing reliable-oriented routing protocols computes link reliability based on the packet reception ratio and neglects impact of various parameters such as noise, shadowing, battery-lifespan, uncertainty and geographic locations. In this paper, we propose a Link Reliable Reactive Routing (LR^3) protocol for WSNs to accomplish reliable and resilience to out-of-order transmission and path diversity at each hop. The log-normal shadowing model is used to estimate link reliability and a back-off scheme is used to determine delay. A new cost estimated to find forwarding nodes on mentor path that includes link reliability, delay, status of queue at forwarding node and packet advancement at the forwarding node. LR^3 is simulated using NS-2 and results show that it outperforms other reactive routing protocols in terms of packet delivery ratio, latency, link reliability and data transmission cost[1] [2].

Keywords

Log-normal shadowing model, mentor node, forwarding node, packet advancement, link reliability

1. INTRODUCTION

Wireless sensor nodes are inexpensive tiny processors, distributed randomly in a geographical region to monitor the event of interest. This has led to installation of miniature sensor nodes in industrial automation process and observe the sensitive parameters of automation process. The sensor devices are used in buildings, smart cities automation, and also in monitoring the railway infrastructure such as rail-track, tunnels, signals, track beds, engine functionality and track disjoints [3]. Each application has a unique set of requirements and constraints, such as lifespan, latency, link reliability, and throughput, and necessitates a reliable routing protocol. An unreliable transmission node failure and delaying results of process or control data may abort industrial application resulting in industrial losses. Timely, reliable data transmission and real-time functionality are technical research goals in Industrial-oriented Wireless Sensor Networks [IWSN] [4]. In WSNs, tiny sensor nodes are randomly distributed in rough terrain, hence they pose great challenges like reliable communication, replenishing energy for nodes, throughput and WSNs have higher error rates than optical communication [5][6]. In addition, wireless links are extremely unreliable [7] [8]. In this work we develop a *L*ink *R*eliability based *R*eactive energy aware Routing LR^3 protocol by considering link reliability, back-off delay and energy cost in selecting forwarding nodes. It inherits and exploit opportunistic routing, link reliability considering battery life-span, noise, location and path-loss exponent and queue level at node, thus achieving optimized one-way delivery delay, higher packet delivery and energy optimization. LR^3 is developed and implemented based reinforce reactive-based routing scheme.

Motivation: Due to simulcast characteristics of wireless communications, a node's data transmission can be overheard by all the neighbor nodes within its transmission range that are involved in advancing the packet. Therefore, opportunistic routing exploits the spatial diversity (more number of good performing neighbor nodes) to improve data transmission reliability against channel variations. First, the mentoring nodes are determined during route discovery phase to mentor the packets to positively advance towards the sink. A mentor path consists of mentor nodes that give a generic guidance for packets making routing decision and selecting appropriate forwarding nodes.

Contributions: Modeling wireless link reliability by considering impact of noise, energy consumption, geographic location and link condition. An effective virtual mentor path that exploit cooperative forwarding opportunities in the discovery of route with minimum overhead. Provide simple and effective procedure to select forwarding nodes along the mentor path, a selection procedure which gives preference to neighbor nodes that offers positive geographic advancement, better link reliability and characterized by Queue Priority Index (QPI). Simulation experiments demonstrate the unique features of Link Reliability based Reactive e Routing (LR^3) Protocol with respect to previous reactive based protocols such as GOR [1], [2] and REPF [9].

Organization: The paper is organized as follows: An overview of relevant research is discussed in Section 2. Background work is explained in Section 3. The problem definition and Mathematical model is presented in Section 4 and Section 5 respectively. The proposed algorithm is explained in Section 6. Simulation parameters and performance analysis are discussed in Section 7. Section 8 contains the conclusions.

2. RELATED WORK

Designing link reliability-oriented and energy aware routing protocol is an important task in WSNs. In Wireless Sensor Networks, nodes are deployed with unequal distance and equal distance [10], and there are various terrain obstacles and changes in terrain. A sink must collect data from sensor nodes without using GPS [11]. A sensor nodes monitor event and transmit sensory data of event, a node spend its energy to transmit, receive data packets. The mathematical expressions are derived in [12] for sensor node energy consumption for transmission, and receive packets in WSNs. A number of energy efficient routing protocols have been designed for WSNs [13] [14] [15][16]. A hierarchical, gradient and cluster based routing protocols was proposed in [17] and [18] that are suitable for handling mobility of the sensor devices and the sink station.

A routing algorithm based on genetic and bacterial foraging optimization technique determines reliable and efficient optimal routing paths in [19]. For data accumulation and aggregation of data in WSNs, there are a couple of cluster based routing protocols proposed in recent years which achieve reliable and timely transmission of data. To form clusters, sensors are partitioned into fan-shaped clusters and to reduce the distance between cluster members and cluster heads, Harmony Search Algorithm (HSA) was developed in [20][21]. Geographic routing with opportunistic routing have attracted research community in recent years. It uses the broadcasting nature of wireless networks to forward data packets to the destination nodes [22] [23]. Opportunistic routing extends the idea of geographic routing[24], where the routing layer identifies a set of candidates forwarders and passes this set to the MAC layer. The MAC layer selects one among the forwarders list depending on the current link reliability [25].

The link quality is based on EAR (Efficient and Accurate link-quality monitor) [26], feedback provided by the physical, link, and network layers [27] and advancements, closest to the destination [28]. To select the best forwarder among the candidate list, a priority timer-based forwarder is chosen among the potential candidates to forward the packets and uses adaptive forwarding path selection to minimize duplicate transmissions [29]. A new timer-based contention scheme: Discrete Dynamic Forwarding Delay (DDFD) is used to refrain from periodic transmission of the beacon message, reduce duplication and collision while selecting a forwarding node [30]. Michele and Rao [28] have used optimum number of hops and average number of neighbour nodes as a metric to select the forwarding nodes. The potential forwarder is selected based on the one-hop packet advancement, Packet Reception Ratio (PRR) in [1], and number of next hops and destination set at each intermediate node in [31].

To minimize rate of packet loss and end-to-end latency, a timely and accurate estimation of the link quality, optimum message overhead and detection of malicious nodes are required. To update link quality, local and global route update techniques and mobile access coordination technique for WSNs are proposed in [32] [33]. To reduce the message overhead while selecting forwarding node. Lu et al.,[34] have proposed binary operator graph based on a tree-structure. In addition to reliable and energy-efficient data transmission it is essential to enhance lifetime of the sink node as it forms a bottleneck zone in a network [35]. By assigning cost to wireless links based on remaining energy at each sensor node[36], the life time of sensor nodes and sensor nodes near to sink can be maximized [37][38][39]. Reliability and energy efficiency are crucial requirements for data dissemination in WSNs. However, there is trade-off between these two requirements. Han et al., [40] have achieved balance between reliability and energy efficiency by adjusting the transmission power. Although these protocols achieves minimum latency and average normalized energy consumption, the impact of noise, location uncertainty, battery lifespan of node have not been considered.

Cluster based forwarding is used to alleviate the problems such as link reliability variation due to channel fading, interference, noise etc., by exploiting cooperative communication. A node in the cluster is assigned with the responsibility of forwarding data packets [41]. To combat channel variation and path-loss breakage, on-demand coordinated forwarding scheme is used wherein a node migrates responsibility of forwarding from unreliable links to more reliable links [42]. A distributed robust routing scheme [43] chooses reliable links cooperatively to enhance the robustness of routing under all kinds of path break between the source and the destination.

For recent mission-critical applications like industrial process automation, electric system automation, air traffic control system, disaster monitoring and nuclear power plant defects analysis systems, the problem is rather a constraint satisfaction problem involving reliable data transmission with minimum hops and energy efficiency[44][45]46][47. Industrial Wireless Sensor Networks (IWSNs) have to provide most reliable, energy efficient and self-diagnosis mechanism for industrial system operation. IWSNs can also provide quick response to real-time queries with necessary and appropriate responses and take over usual Industrial Wired Communication Systems [3] [4] [48].

The routing guidelines to design routing protocol for real-time application in terms of expected throughput, transmission delay, reliability, and optimal sensor node energy usage for IWSNs are presented in [49][50]. A routing protocol for IWSNs is presented in [51] that attains energy-efficiency, and reliable data transmission for real-time traffic. Recent works [52] [53] have presented routing schemes for reliable data transmission with energy efficient communication for industrial networks.

It is essential to design routing protocols that refrain channel variation and meet real time reliability and timeliness constraints in simple yet effective energy efficient way. In this work, wireless link reliability is modeled by considering various transmission impairments on wireless link, reactive routing scheme discovering a mentor path such as cooperative forwarding opportunities in the route discovery phase with low overhead. The selecting forwarding node along the mentor path that offer a positive geographic advancement, better link reliability and characterized by Queue Priority Index (QPI).

3. BACKGROUND

Jian et al.,[2] proposed a reliable-oriented Reliable Reactive Routing Enhancement (R3E) protocol to achieve reliable, delay-aware and energy efficient communication under lossy and dynamic wireless links. R3E finds the guide node that gives direction to the sink during route discovery. It works on back-off delay scheme wherein any candidate node which receives packet could send acknowledgment to inform the sender that it is a high prioritized node and it can be considered as next potential forwarder. However, R3E leads to significant energy cost due to broadcasting RREQ message to all the nodes of network and back-off scheme calculation does not consider the impact of noise, location of node, path-loss exponent on link while finding the link quality. It suffers from delivery latency when it encounters a congested node as the next the forwarding node.

4. PROBLEM STATEMENT

4.1 Problem Statement

A group of homogeneous sensor nodes form a network and is described as a graph $G= (SN, L)$ where sensors are denoted as vertices SN, an edge L created for two distinct node SN_i and

SN_j. A sensor device *i* is transmits a sensed message to the destination device (indicated as *Dest*), and the sensor node *j* is a neighbor node of *i*. C_i is represented as the accessible set of next-hop nodes of node *i*. Let F_j ($F_j \subseteq C_i$) represent the selected group of forwarding potential candidates for sensor node *i*, and is associated in the local packet forwarding responsibility. Each forwarding candidate node is characterized by *Back-off delay, link quality* and *packet advancement*. The *back-off, wireless link reliability* and *packet advancement* are used as cost functions to determine the forwarding nodes.

4.2 Problem Formulation

The problem is formulated as a reliable and energy efficient routing path construction with multi-constraints optimization problem.

Problem Formulation: $F_j \subset C_i$

$$\text{Such that } \max \ Padv_i\left(i, F_j\right)$$

$$Max \ \Pr_{i,Fj}(d)$$

$$Min \ D_{i,\ F\ j}$$

$$Dist(i, F_j) \le T_{range}$$

4.3. Objectives

The objective is to design a reactive routing protocol to select a forwarding node that combats the channel variation by exploiting spatial diversity to accomplish maximum packet advancement towards sink, efficient utilization of sensor node's energy, timely delivery of packets with optimum number of nodes and accurately estimate link reliability by considering impact of noise, location of node and path-loss exponent. The selected forwarding node must result in packet delivery ratio and reduce the cost of forwarding.

5. SYSTEM MODEL

5.1 Back-off Delay

$D_{i\,Fj}$ represent delay at the jth forwarding candidate node when it has received the packet. It is calculated as in Equation (1).

$$D_{iF_j} = \frac{Hopcount}{\sum_k P_{ik} \times P_{kj} + 1} \times \upsilon \qquad (1)$$

Where υ represents a slot unit and P_{ik} represents link reliability between sensor node *i* and sensor node *k*.

5.2 Link Reliability

The impact of shadowing, battery life-span, noise and geographic position of sensor node are considered for modeling reliability of wireless link. In wireless communication, the received signal strength reduces as it travels from sender to the receiver. This process is known as path-loss, and the attenuation of signal is because of path-loss phenomenon and is given by the Equation (2).

$$PL(d)_{dB} = PL(d_o) + 10_{n\log 10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad (2)$$

Where d_o is the reference distance, the X_σ is the zero mean with variance σ^2 variable and *d* is distance between the sender and the receiver. In presence of path loss-exponent, the probability of receiving a packet successfully at a node is given by Equation (3).

$$P_{i,F_j} = (1-P_e)^{8(fr-l)} = (1-P_e)^{8f}$$

(3)

Here, *f* is the size of the frame, *l* is the preamble length and P_e is the bit error probability i.e.

$$P_e = \frac{1}{2}\exp^{\frac{-\alpha(d)}{2}} \qquad (4)$$

The α is SNR at distance *d* and is given by equation (5)

$$\alpha(d) = P_{tdB} - PL(d)_{dB} - P_{\varepsilon dB} \qquad (5)$$

Thus, probability of the packet received successfully at the receiver is given by Equation (6).

$$\Pr_{i,F_j}(d) = \left(1 - \frac{1}{2}\exp^{\frac{-\alpha(d)}{2}}\right)^{8f} \qquad (6)$$

Wireless radios do not provide the value of α , but provide the *RSSI.* The *RSSI* measurements is used to find the *SNR*, thus, Equation (6) is rewritten as

$$\Pr_{i,F_j}(d) = \left(1 - \frac{1}{2}\exp^{\frac{-\alpha(d)}{2}\frac{1}{0.64}}\right)^{8f} \qquad (7)$$

5.3 Packet Advancement

Packet advancement offered by the forwarding candidate node is defined as follows:

$$P_{adv}(i, F_j) = Dist(i, Dest) - Dist(F_j, Dest) \quad (8)$$

$Dist(i,\ Dest)$ is the Euclidian geographic location between the sensor node *i* and the *Dest.*

Let $\prod(F_j)$ = $j_1, j_2, .. \ j_k$ be possible set of forwarding candidate nodes. From this set, a forwarding candidate node that achieves expected back-off delay, link reliability and packet advancement for node i are ordered in ascending in the set *π(Fj).* The expected back-off delay $\exp_d(\prod F_j)$, packet advancement $\exp_a(\prod F_j)$ and link reliability $\exp_r(\prod F_j)$ are shown in equation Equations (9)(10)(11) respectively.

$$\exp_d(\prod F_j) = \sum_{k=1}^{n} D_{iFj_k} \ \Pr_{(i,Fj_k)}(d) \prod_{m=0}^{k-1} \overline{\Pr_{(i,Fj_k)}}(d) \quad (9)$$

$$\exp_a(\prod F_j) = \sum_{k=1}^{n} P_{adv}(i, F_j) \ \Pr_{(i,Fj_k)}(d) \prod_{m=0}^{k-1} \overline{\Pr_{(i,Fj_k)}}(d) \quad (10)$$

$$\exp_r(\prod F_j) = 1 - \prod_{m=1}^{n} \overline{\Pr_{(i,Fj_m)}(d)} \quad (11)$$

The objective of the problem statement is to select j_k^{th} mentor node from (F_j)) that is assigned the task of forwarding and is obtained as follows

$$\prod_{j_k} F_j = \frac{P_{adv}(i,F_j) \times \Pr_{i,F_{jk}}(d) \prod_{m=0}^{k-1} \overline{\Pr_{i,F_{jm}}}}{\sum_{k=1}^{n} D(i,F_j)} \quad (12)$$

6. ALGORITHM

Route Request (RREQ) Propagation: When the node *i* has sensor data and is ready to transmit a sensed information to the sink node, it determines the mentor node in the route request phase as described in *LR^3: RREQ Route Request phase* algorithm. Node i sends *RREQ* message to its one-hop neighbours i.e. $j \in N(i)$, the neighbor nodes that receive non-duplicate *RREQ* checks whether it is the intended destination or not. If it is not the intended destination then it determines the common neighbours between i and j and stores it in common neighbour set CN_i. Let node k belongs to common neighbour set CN_i, for each node k the node i computes Queue Priority Index *(QPI)* and link reliability P_{ik} and P_{kj}.

The nodes of common neighbor set CN_i that are not satisfying the threshold link reliability i.e. $\left(P_{ik}(d) \times P_{kj}(d)\right) \geq 0.5)$ are discarded, and the remaining nodes of common neighbor set CN_i are called as potential nodes F_j For each potential node F_j, the packet advancement $P_{adv}(i,F_j)$ is calculated. We define $\prod_k F_j$ as one-hop progress at current neighboring node *j* given set of potential nodes F_j, and is calculated by dividing packet advancement and link reliability i.e. $\left(P_{adv}(i,F)_j \times \left(\mathrm{P}_{ik}(d) * P_{kj}(d)\right)\right)$ by back-off delay, as in Equation (12). After computation, a potential node j_k that has higher progress is designated as *mentor node* and node j_k rebroadcast *RREQ* with mentor *node ID* and *RREQ sequence number*.

Increase in one-hop progress can meet end-to-end latency and reliability requirements. In Case, each potential nodes that belongs to *CNi* does not satisfy the link reliability threshold value, then the progress of potential node is computed dividing packet advancement (i.e. P_{adv} (I, Fj) by the *back-off delay*. A potential node j_k that has higher progress is designated as *mentor node* and node j_k rebroadcast *RREQ* with mentor node *ID* and *RREQ sequence number*. The time complexity of the proposed protocol is of order *O (|CNi|)*.

Route Reply (RREP) Propagation: LR^3: *RREP Route Reply phase algorithm* notifies *mentor nodes* on reverse routing path and the set of common nodes in collegial forwarding. When a node receive a *RREP* packet from the destination (or upstream node) and if it knows that it is a *mentor node* on the routing path, it adds its upstream and downstream *mentor nodes ID* to *RREP* and advances *RREP* towards the source node. Thus, the *RREP* is proliferated by a mentor node in till it reaches source node along the reverse routing path. Due to the broadcast nature of wireless link, a common neighbor nodes *(CN_i)* may also overhear *RREP* packets (common neighbor node is not mentor node), it adds the *upstream, downstream nodes'ID* and other common neighbor nodes on the routing path to its table. The common neighbor node discards the *RREP* packet since it is not mentor node to forward the packets. The proposed protocol is tolerant to failure of *RREQ* and *RREP*, since the next prioritized common neighbor node can be selected as a mentor node in the route request phase.

Example: The selection of mentor node is analyzed and illustrated in *Figure 1*. Let the node *S* send a sensed data to the destination *dest*. The sensor node *C* is identified as Mentor node and it has four available common neighbors between itself and the source node *S* i.e. *A, B, W, X.* We set the link reliability values based on the simulation using *NS-2* simulator and are shown in flower brackets. For example, node *A* has {0.8, 0.6} which indicates that *Pr(S, A) =0.8, Pr (A, C) =0.6*. The packet advancement value is indicated in a simple bracket. The node *A* has P_{adv}*=10*, when Node *C* receive *RREQ* and assumes itself as mentor node, *S* is a upstream node, nodes *A, B, W, X* are common neighbor nodes. C has higher value, and hence rebroadcast *RREQ*.

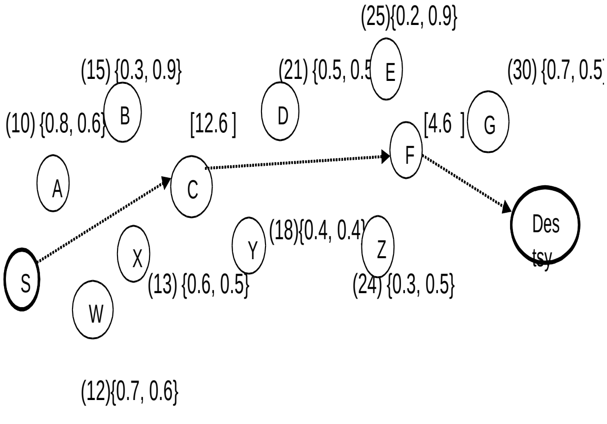


Figure 1: An example illustrates the forwarding node selection scheme. The *RREQ* travels through *S → C→ F → Des*

Algorithm 1: LR^3: *RREQ:*Route Request Phase

```
Procedure: rcvRREQ(packet *P)
Data: sensor nodes $SN_i..SN_k..SN_j$, $N_q$, Q, M
Result: Set of Mentor Nodes
if Non-redundant RREQ at $SN_j$ then
    if ($SN_j \epsilon N(SN_i)$ is the sink node) then
        reply with RREP ;
    else
        $CN_{(i,j)}=SN_i \cap SN_j$;
        for Each node k ϵ CN(i,j) and $E_k \geq \xi$ do
            add k to $CN_i$
        end
        for (Each node k ϵ $CN_i$ ) do
            Find QPI(k)=min((Nq-Q/M), Nq)
        end
        for Each potential nodes $F_i \subset CN_i$ do
            Find Back-off delay $D_{ij}$ Find $P_{adv_{ik}}$
            Find $Pr_{i_kj}(d')$
        end
        for Each potential candidate nodes $F_i \subset CN_i$ do
            if { $Pr_{i_kj}$(d') ≥ 0.5} then
                $\pi_k(F_i)) = \frac{(P_{adv_{ik}} \times Pr_{i_kj}(d'))}{\Sigma_{k=1}^{n}(D_{i_kj})}$
            else
                $\pi_{jk}(F_i)) = \text{MaxMin}\left(D_{i_kj}, P_{adv} i_k\right)$
            end
        end
        if (~ $CN_i$) then
            forward RREQ(p)
        end
        return F /* mentor node */
    end
else
    Drop(p);
end
```

Algorithm 2: LR^3:*RREP*Route Reply Phase

```
Procedure: rcvRREP(packet *P)
if Non-redundant RREP then
    if ($F_j$ = = $F_{i-1}$ ) then
        send RREP to $F_{i-2}$
    else
        add $F_{i+1}$,$CN_{(i,i+1)}$,$F_i$ and,$CN_{(i-1,i)}$
        Discard(p)
    end
else
    Drop(p)
end
```

7. PERFORMANCE EVALUTION

In the following section, the proposed protocol LR^3 performance is analyzed and simulation results are compared with other routing schemes; AODV-R3E [2], GOR [1]. The LR^3 performs fair well with respect to packet delivery ratio, end-to-end delay, number of forwarding nodes and link reliability. Simulations have been carried out using ns-2 [54] with C++ code [55].

7.1 Simulation Parameters and Assessment Metrics

Table I: Simulation Table

Parameters	Symbol	Value
Simulation area	Sq.mt	200*200
Transmission range	r	50m
Power required for sensing	e^{sens}	0.1mW
Power dissipation to operate t	E^{ele}	0.1mW
The starting energy of a node	E^{init}	0.05J
The threshold energy of a node	E^{th}	0.001J
Packet length	L	40,80 bytes
Data rate	dr	25 kbps
Reliability Requirment	R_{rq}	0.99
Destination node position	Dest	(0,0)
Source node position	S	(200,200)
End-to-End Delay	D_{rq}	0.12s

(i). End-to-end packet delivery latency: The end-to-end transmission delay or one-way delay is defined as the total time needed for a packet to arrive at the destination after it is broadcast at the source node.

(ii). Packet Successfully Delivered Ratio: it is described as the ratio of the total number of successfully arrived packets at the sink node and to total number of the packets commissioned from the source.

(iii). Data Transmission Cost: is the amount of transmissions required for a packet successfully delivered from the sender to the receiver.

(iv). Link reliability: It is the quality of link between each sensor node for successful data transmission. (v). Number of forwarding nodes: The total number of reliable and energy efficient forwarding nodes on a path to relay data packets.

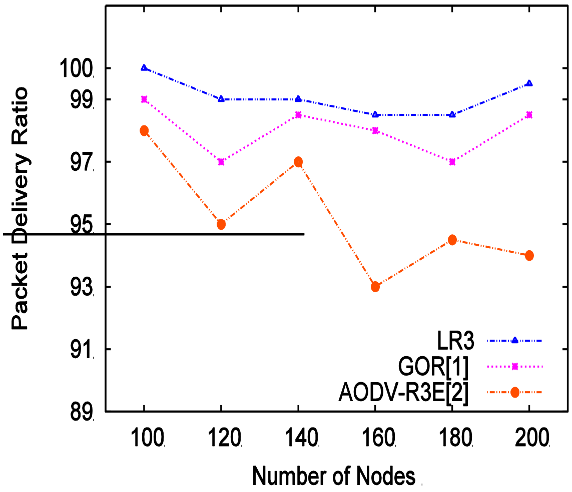


Figure 2: Packet Delivery Ratio for 200-nodes Net- work, and only successful transmissions are used.

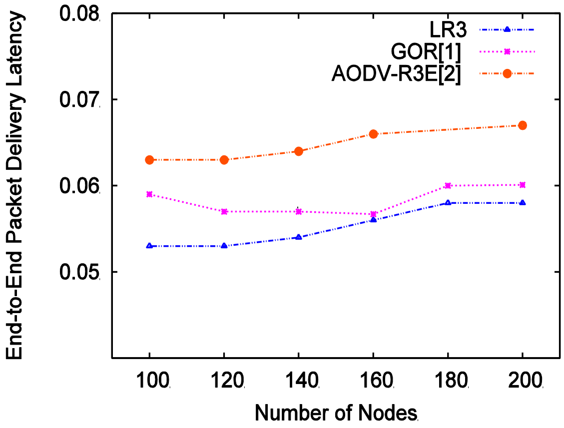


Figure 3: Average Packet Delivery Latency for varied number of sensor nodes.

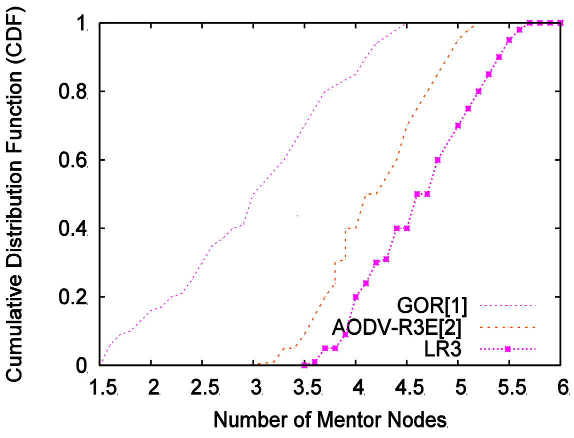
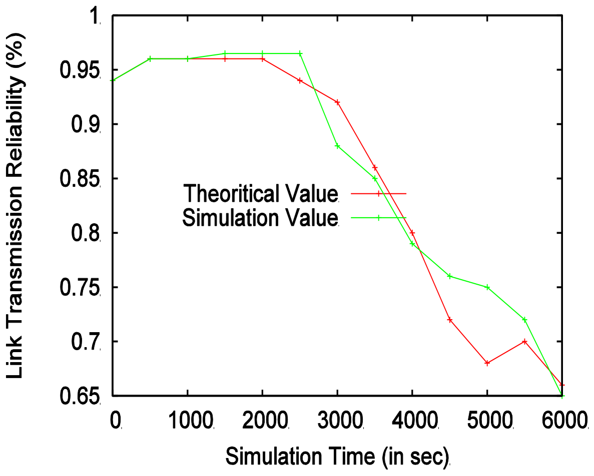
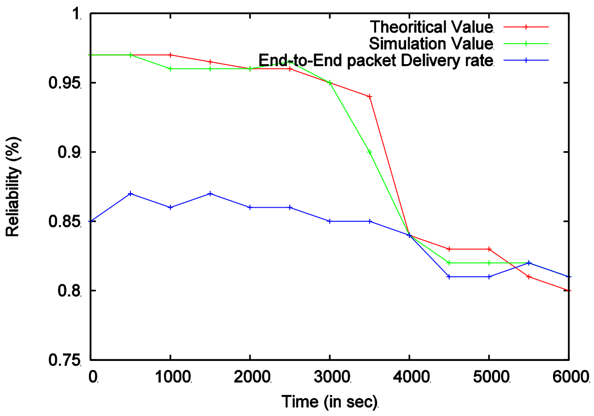


Figure 4: Cumulative Distribution Function of the mentor nodes at each hop.



(a) Link Transmission Reliability under different traffic load



(b) Link probability with log-normal shadowing radio model

Figure 5: Link reliability as a function of the normalized distance and for different value of ξ

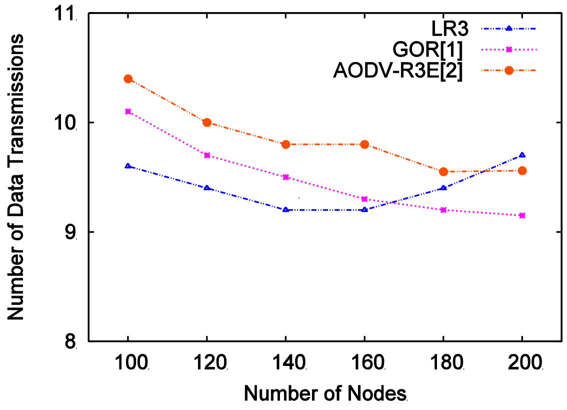


Figure 6: Data transmission cost

The packet successfully delivered ratio under varying number of sensor nodes is illustrated in Figure 2. The packet delivery ratio in LR^3 is about 95% for different node densities. The proposed protocol LR^3 selects a mentor node that has maximum progress which is computed based on back-off delay, link re- liability and packet advancement of common nodes. In LR^3, the link reliability value is measured by considering effects of noise, location, path-loss on wireless link, and the queue status at each common node. Geographic Opportunistic Routing (GOR) [1] scheme determines link reliability by use of probe packets, and that does not reflect actual link reliability. Therefore, packet delivery ratio decreases with increase in node densities. AODV-R3E [2] selects the forwarding node based on back-off delay, which is computed based on packet reception ratio of the probe packets. AODV-R3E selects the forwarding nodes that might be congested and incur high transmission error that results in lower packet delivery ratio with change in node densities.

The average packet delivery delay of LR^3 and other protocols under different node densities is depicted in Figure 3. The one-way delay incurred due to non-available reliable nodes along the path is the end-to-end transmission delay. GOR [1] incurs more delay due to non-availability of reliable forwarding nodes and selection is based on geographical progress of packet. Therefore, it results in re- transmissions and increase in the end-to-end delay. AODV-R3E [2] induces more delay due to selection of congested and high transmission error forwarding nodes on the path. AODV-R3E has optimum end- to-end delay because the node that has low back-off delay rebroadcasts RREQ packet and is identified as guide node on path. In LR^3, end-to-end delay is comparatively low because link reliability is modelled accurately by considering link uncertainty condition, shadowing, path-loss exponent, and queue status at each node. LR3 alleviates nodes that experiences higher error in packet transmissions and back-off delay. Packet advancement offered by the common nodes are taken into account in mentor node selection. Therefore, LR^3 has reliable and energy efficient mentor nodes along the path. LR^3 routes are more progressive and it incurs low latency because of its reliable mentor nodes on the path. The protocols in [2] and GOR [1] have congested forwarding nodes along the path that induces significant latency.

Figure. 4 illustrates the cumulative distribution function for the number of forwarding nodes in GOR [1], AODV-R3E [2] and LR^3 protocol. In GOR, the forwarding node selection is based on the greedy approach and uses one-hop neighborhood information. GOR does not guarantee the selection of optimal routing path, and the number of forwarding nodes are less. AODV-R3E [2] uses cooperative opportunistic approach in route establishment and it has optimal number of forwarding nodes. AODV- R3E has 3 to 5 forwarding nodes whereas GOR has 2 to 4 while the proposed protocol LR^3 has 3.5 to 6 forwarding nodes at each hop. The reason is that LR^3 protocol keeps all information such as link reliability between nodes, queue status at a node, offered packet advancement and propagation delay. Therefore, the cost function reduces due to selection of the best mentor nodes on the path.

Link transmission reliability is plotted in Figure 5(a). The theoretical value and the simulation values have downward trend with the progress of simulation time. The reason is that the nodes generate huge traffic and the congestion within the network is serious with the progress of simulation time. Additionally, as time progress, the reliability of the sensor nodes decrease and indicate the failure of nodes on path. The end-to-end packet successful delivery rate deteriorates rapidly with the progress of simulation time.

Figure 5(b) illustrates the modeling of link re- liability under path-loss exponent, noise, energy consumption and uncertainty condition of link. The performance of the proposed protocol LR^3 depends on link reliability as it is blended with the selection of node's mentors list. The link probability is calculated by changing the values of ξ, and the normalized distance between the nodes. ξ represent the ratio between shadowing and path exponent value of ξ and is varied between 0 to 6.

Figure 6 illustrates the cost of data transmission. The data transmission cost is directly proposition to the number of hops on the path. In LR^3, it is expected that the mentor node with high link reliability and optimum packet advancement are chosen. Therefore, the cost of data transmission is almost maintained constant though there is increase of nodes in network. GOR [1] exploits the spatial diversity and selects the forwarding node that have maximum packet advancement without considering the link reliability condition. Therefore, the routing paths have optimum number of hops and lower data transmission costs compared to LR3 and AODV-R3E [2]. AODV-R3E data transmission cost is expensive compared to GOR and LR^3 because it considers the *PRR* of neighbors but not packet advancement. Considering the average number of packet re-transmissions due to unreliable link between the sensor nodes, the cost of data transmission is higher in AODV-R3E protocol than LR^3.

8. CONCLUSIONS

In this paper, we have designed and assess the Link Reliable Reactive Routing (LR^3) protocol that delivers the sensed data most reliably and with optimum delay. The log-normal radio model is used estimate link reliability. Each prospective forwarding/mentor nodes is characterized by the queue priority index (QPI), back-off delay, and packet advancement. The data packets transferred along the mentor path is resilient to transmission failures of *RREQ*, *RREP* since there are a large number of disjoint paths. Simulation results illustrate that the designed protocol LR^3 delivers data reliably with low energy consumption and within time-line, and outperforms [1][2] in terms of packet delivery, energy efficiency and link reliability.

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