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Reliable Adaptive Replication Routing for Wireless Sensor Networks

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ABSTRACT

In this paper, we consider the problem of reliable communication, the packet-loss prevention and packet-loss recreation recovery techniques are widely used and have many practical challenges. Hence, we propose a Reliable Adaptive Replication Routing (RARR) Algorithm, here the packet loss replication is accomplished in several hops and End-to-End (E2E) reliability is improved compared to conventional single E2E paths. RARR algorithm is comprised of a link capacity estimator, random disseminator and a replicator. The protocol employs an adaptive neighbor knowledge scheme which differentiates the density of nodes in the deployed scenario and hence reduces the overheads compared to the existing Proliferation Routing scheme. Simulation results demonstrate the effectiveness of this scheme and show that the proposed protocol is a feasible solution to increase the service quality (i.e., E2E transmission success rate, energy efficiency) compared with the well-known routing techniques. The proposed protocol is scalable and practical, and it dynamically adapts to the network topology.

Keywords:

Reliability, Packet Reception Ratio (PRR), End-to-End success rate, Energy Efficiency, Node Density, Service Quality, Wireless Sensor Networks (WSNs)

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are comprised of a large number of irreplaceable, battery-powered devices, scattered densely and randomly in a geographical area of interest. In general, the sensors in a WSN sense and gather data from surrounding environment and transmit it to nodes, called sinks, to perform more intricate processing.

WSNs have not only stretched the horizon of traditional sensor networks, but also proliferated significantly to a variety of novel applications. Recent years have witnessed the deployments of WSNs for a class of real-time critical applications, including search and rescue, health care, scientific research, industrial, security surveillance, traffic and environmental monitoring, wild animal tracking, disaster management, and household monitoring. With WSNs, it is possible to assimilate a variety of physical and environmental information in near real time from inaccessible and hostile locations. To ensure widespread deployment and popularity, emerging WSNs will require a set of QoS requirements, particularly reliability, timeliness and energy. Reliability is defined in terms of the ability to deliver data to the destination with minimum packet loss. For example, applications, such as forest fire detection, may require that packets to reach the destination or monitoring station without any loss. Again, based on the content of sensed data, different reliability constraint is needed to be imposed. For example, in fire-monitoring applications, temperature information about the regions which have normal temperatures can endure a certain percentage of loss. On the other hand, sensor data containing information about the regions which are experiencing abnormally high temperatures should be delivered to the control center with a high probability of success, as it can be a sign of fire [1]. To assure such a lossless data transaction, prioritized forwarding or multi-path routing can be adopted. Sending copies of the same packet over different paths increases the probability that at least one of the copies reaches the sink correctly [2].

Several other factors, such as the random nature of the communication channel, collision, congestion and the presence of interference, affect the reliability in wireless sensor networks. The study of reliability in wireless sensor networks is a critical aspect for designing network architectures suitable for real time wireless sensor applications and hence calls for extensive work in this area. Our proposed protocol is motivated primarily by the deficiencies of the previous works (explained in the Section 2) and aims to provide better reliability.

Existing works attempt to provide improved reliability by packet-loss prevention (e.g., [3][4]) and packet-loss recreation (e.g., [5]) techniques which can be achieved in a per-hop or end-to-end (E2E) manner. These recovery techniques have practical challenges that include long transmission paths, radio interference, packet collisions and bad link propagation due to unreliable links. These techniques perform well in a small-scale network but when the network scales up, their efficacy in improving the reliability is reduced due to collisions and congestion. To resolve these challenges this paper proposes an Reliable Adaptive Replication Routing (RARR) algorithm, here the packet loss replication is accomplished in several hops and E2E reliability is improved compared to conventional single E2E paths. The protocol employs an adaptive neighbor knowledge scheme which differentiates the density of nodes in the deployed scenario and hence reduces the overheads during the replication phase.

Reliable Adaptive Replication Routing (RARR) algorithm is comprised of a link capacity estimator, random disseminator and a replicator. The link capacity estimator is responsible to find reliable routing paths for the packets. The random disseminator aids in finding disjoint routing paths based on the density of the nodes, in a manner which will reduce collisions and interference in the network. The replicator produces copies of the data packets in a controlled fashion.

We test the performance of our proposed approaches by implementing our algorithms using ns-2 simulator. Our results demonstrates the performance and benefits of RARR over earlier algorithms.

The rest of the paper is organized as follows: A review of Related Work is presented in Section 2. Network model, notations, assumptions and working of the algorithm are explained in Section 3 and Section 4. Simulation and Evaluation of the algorithm are described in Section 5. Conclusions are summarized in Section 6.

2. RELATED WORK

Maintaining a reliable network connection has been a fundamental problem in networking. With current demands for high network reliability, it is imperative to understand and quantify reliability for network design. There has been extensive research in this area; current works can be classified as packet-loss prevention and packet-loss recreation methods.

Packet-loss prevention methods employ more productive forwarding nodes or select multi-path transmissions to improve the packet success rate. GRAB [4], Direct Diffusion [6], ReINFORM [7] spawn more transmissions to enhance the transmission quality. In these methods there is no control when a failure occurs on a specific data path and will eventually result in lower E2E delivery rate.

In probabilistic approaches, when a node receives a packet, it forwards the packet with probability p. The value of p is determined by relevant information gathered at each node. Simple probabilistic approaches, such as (e.g., Gossip [8][9]), predefine a single probability for every node to rebroadcast the received packet. This scheme can lead to both the broadcast storm or the die out problem. Gossip approaches can be considered as an efficient flooding with reduced redundant forwarding. Though regional gossip can constrain the flooding within a certain region, it is still costly in terms of network resources. Vadim *et al.*, [10] propose three common approaches for achieving scalable reliable broadcast in wireless ad hoc networks, namely probabilistic flooding, counter-based broadcast, and lazy gossip. The strength and weaknesses of each scheme are analyzed, and a new protocol that combines these three techniques is developed. They focuses on the trade-offs between reliability (percentage of nodes that receive each message), latency, and the message overhead of the protocol.

Gandhi *et al.*, [11] present a simple 12-approximation algorithm for the one-to-all broadcast problem. They present two algorithms with approximation ratios of 20 and 34, obtaining excellent results. Fu-Wen *et al.*, [12] address the issue of broadcasting over both reliable wireless links and unreliable wireless links. The problem of the minimum transmission broadcast problems over reliable links and over unreliable links is formulated as two mixed integer linear programming (MILP) problems, respectively. This way, optimal broadcast schemes can be easily obtained using any existing MILP solver, for small-scale networks. For large-scale networks, they propose a distributed game-based algorithm and prove that the game-based algorithm achieves Nash Equilibrium. Yi *et al.*, [13] propose a quality-of-service (QoS)-based broadcast protocol under Blind Information for multi-hop CR wireless ad hoc networks, with the aim of having a high success rate and short broadcast delay.

Packet-loss recreation (e.g., PSFQ [5][14]) techniques which can be achieved in a per-hop or end-to-end (E2E) manner. Retransmissions are carried out to recover the packet loss in this scheme. E2E recovery, that are adopted in classic networks, is inadequate for WSNs unless the big delay and the high energy cost are admissible. Recent research efforts are focused on the efficient packet-loss detections and recreation. Though in theory loss-free communications can be provided by unconstrained retransmissions, in practice, however, unlimited retransmissions are prohibitively costly. In a long-path transmissions, errors will be accumulated and finally arrives to an unacceptable level. Therefore, using per-hop recovery to guarantee service quality for long path transmissions is neither efficient nor practical.

Diverse routing schemes like opportunistic routing [15][16] do not absolutely assign the routing path but the selection of the next-hop forwarder is done in an implicit manner. A transmitter simply broadcasts the packet in nearby neighborhood. The successful receiver with the ideal path to the destination will be the preferred forwarder. When used with network coding techniques [16], the set up cost is immensely decreased. The idea of opportunistic routing is more on the routing path choice and transporting data in an ideal way. The reliability and fault-tolerance aspects of the packet routing is not considered. Nazanin *et al.*, [17] propose a scalable approach for reliable and energy-efficient broadcasting in a multi-hop wireless sensor networks that also addresses load balancing, while requiring no knowledge of network topology. CRBcast combines the energy-efficiency offered by probabilistic broadcasting (PBcast) with the reliability features offered by application-layer rate-less coding.

Yunhuai *et al.*, [18] propose proliferation routing, to some extends, like ant-routing [19] and probabilistic flooding. The design aspects are however different. The concept of ant routing was to exploit the network dynamics by using a stream of data packets. The objective was to maintain ample information to the nodes for different data paths when the main paths deteriorate. Proliferation routing aims at reliability-oriented transmission service for each data packet. The method endeavors to enhance the endurance of the packets so that long term transmission success rate is attained.

The protocol proposed in this paper is different from Proliferation Routing in that it considers an adaptive density metric which differentiates the density of nodes in different areas of the network and aids in reducing or increasing the random walk steps which is effective in improving the end-to-end success rate and reducing the collisions in the network.

3. NETWORK MODEL AND PROBLEM DEFINITION

In this section, we discuss the network model, assumptions used in this paper and we define the problem in hand.

3.1 Model and Assumptions

In our network model, we assume the following:

—The wireless sensor nodes consists of N sensor nodes and a sink, the sensors are distributed in a non-random manner with varying densities in the field are assumed to be stationary.

—The N sensor nodes are powered by a non renewable on board energy source.

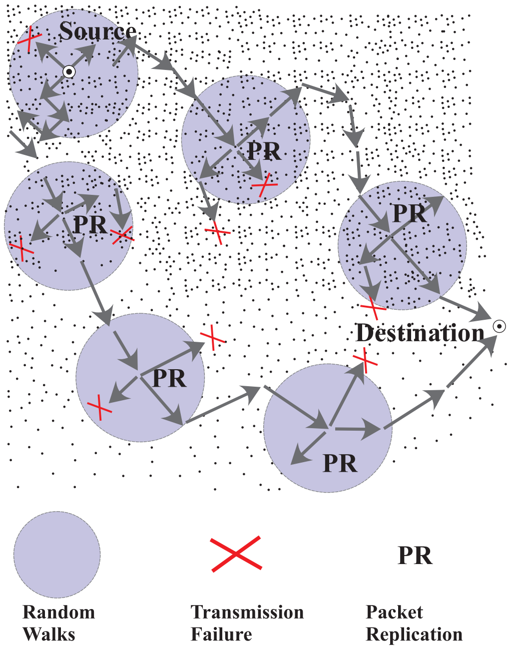

Fig. 1. Description of Random Walks and Packet Replicator

Table 1. Notations used in Section 4

Symbol	Definition
N	Set of Nodes in the WSN
S	Source Node
D	Destination Node
$N_1(p)$	Set of one-hop Neighbors of node p
$N_2(p)$	Set of two-hop Neighbors of node p
prr_{pq}	Packet Reception Ratio of link relaying node p to node q
$CAP(p)$	Capacity of a node p
β	Packet life span
μ	Random Walk step factor
π	Replication factor
TTL_{ls}	Packet Life Span - Time to Live value (β)
TTL_{rw}	Random Walk - Time to Live value (μ)
d	Average node density
$DM(p)$	Density Metric of node p = $N_2(p)$ / $N_1(p)$
δ	Random Walk increment/decrement step value
S	End-to-End transmission success rate in %
EF	Energy Efficiency in %
α	Communication overhead
ρ	Fixed success rate of all links

—Additionally, each node is aware of its one-hop and two-hop neighbors *via* Hello packets.

3.2 Problem Definition

The topology of a wireless sensor network may be described by a graph $G = (N, L)$, where N is the set of nodes and L is the set of links. The objectives are to,

—Maximize the end-to-end transmission success rate and hence improve the reliability.

—Improve the energy efficiency of the network.

4. ALGORITHM

Unlike the per-hop and end-to-end (E2E) recovery techniques, the proposed RARR provides an intermediate multi-hop recovery approach. Several data packets originate from the source S towards the destination D. The packets are disseminated in an arbitrary fashion based on the density of the nodes in the network. Disparate routing paths selected during this process results in lowering the collisions and prevent hot spots in the network. The data packets travel a finite number of hops called a life span and reach a $replicator$ node, which produce several copies of the data packets based on the required E2E success rate and data path length as shown in Fig. 1. During this approach many packets are lost during the transmission in various paths but when a packet successfully reaches a replicator node the production of multiple copies balance this loss.

The notations used in this paper are given in Table 1. The protocol consists of the following: (a) Link Capacity Estimator; (b) Packet Disseminator; and (c) Packet Replicator.

4.1 Link Capacity Estimator

The $link\ capacity\ estimator$ provides a metric to each node that emulates the transmission success rate from the node to the destination by a single path. The metric is calculated from the packet reception ratio (PRR) and the capacity value of each node. The Packet Reception Ratio (PRR) of the link relaying node p to q is denoted by prr_{pq}, it denotes the probability of successful delivery over the link. The PRR is obtained using the Window Mean Exponential Weighted Moving Average (WMEWMA) based estimation. Foremost, the destination node has capacity value of 100 and all other nodes have capacity value of 0. The neighboring nodes of the destination or sink node are able to calculate their capacity value i.e.,

$$CAP(q) = CAP(q) \times prr_{pq} \tag{1}$$

Then, the two-hop neighbors of the sink calculate their capacity based on the one-hop neighbors of the sink and so on till all nodes obtain their individual capacity. After the packets are sent on different routing paths by the random disseminator and reach the end of their random walks. The node r with the largest capacity (Eqn. 2) for p is chosen as the forwarder and the process continuous till the destination is reached.

$$r = \arg\max_{q} CAP(q) \times prr_{pq}\ \forall q \in N_1(p) \tag{2}$$

4.2 Packet Disseminator

The multi-hop recovery approach requires to reduce the collisions, re-transmissions and interference between the various data paths created during transmission. The $packet\ disseminator$ fulfills this purpose by finding disparate paths based on the density of the neighborhood. We propose that the path length set for the packets in the random walk phase should be set in proportion to the size of its neighborhood. Proliferation routing only considers the average node degree of the network while deciding the length of the random walk steps (μ).

The packet life span (TTL_{ls}) in the disseminator has two stages, the random walk stage and the definite walk stage. In the random walks, the packets travel the network from node to node in a random fashion governed by TTL_{rw}. The TTL_{rw} is decremented at every hop and when its value hits zero the packet concludes the random walk stage. In the next leg, the nodes invoke the link capacity estimator to identify the next node in the path. When the packet life span TTL_{ls} hits zero, the packet completes the two stages of the disseminator and enters the $replicator$ phase. (Algorithm 1)

Algorithm 1: Reliable Adaptive Replication Routing (RARR)

```
Input: node $p$, Packet, $N_1(p)$
Output: A Node $q \in N_1(p)$ to forward the Packet OR $\pi$ nodes from
        $N_1(p)$ to forward the Packet
for each Packet in node $p$ do
    $TTL_{ls}$ = $TTL_{ls}$ - 1;
    if $TTL_{ls} > 0$ then
        $TTL_{rw}$ = $TTL_{rw}$ - 1;
        if $TTL_{rw} > 0$ then
            Forward packet to a random node $q \in N_1(p)$;
        else
            Forward packet to a node $r$ with $\arg\max_q$ CAP(q) $\in$
            $N_1(p)$;
    else
        Compute $\pi$ and $\beta$ from $\binom{\pi}{n}(\rho^{\beta})^{n}(1-\rho^{\beta})^{\pi-n}$ based on $s$
        $TTL_{ls}$ = $\beta$;
        DM(p) = $N_2$(p) / $N_1$(p);
        $\delta$ = 1;
        for each $\pi$ random nodes $\in N_1(p)$ do
            DM($q_\pi$) = $N_2(q_\pi)$ / $N_1(q_\pi)$;
            if (| DM(p) - DM($q_\pi$) |) > 1 then
                $\mu_\pi$ = $\mu_\pi$ - $\delta$;
            else if (| DM(p) - DM($q_\pi$) |) < 1 then
                $\mu_\pi$ = $\mu_\pi$ + $\delta$;
            else
                $\mu_\pi$ = $\mu_p$;
        Reset $TTL_{rw}$ = $\mu$ for all $\pi$ packets;
        Forward packets to $\pi$ selected random neighbors $\in N_1(p)$;
```

The critical design aspect in the disseminator is the region in the network over which the random walks occur. The random walk step value μ has to be tuned in a way that packets do not reach the same node at the end of their walks; this helps to minimize collisions and reduce energy consumption. In Proliferation routing, based on the authors analysis, the value of μ is chosen as 4 for a moderate node density of d = 9. But, this constant value does not work effectively if the network is not uniformly populated.

Hence we propose a density metric which differentiates the density of nodes in different areas of the network and modifies μ in an adaptive manner which is proportion to the size of the neighborhood. We calculate the density metric which computes the density of the two hop neighborhood of a node i.e.,

$$DM(p) = N_2(p)/N_1(p) \tag{3}$$

where, $N_1(p)$ and $N_2(p)$ are the one-hop and two-hop neighbors of p. The density metric of prospective forwarding nodes are also computed. The random walk step value μ is reset based on the density of surrounding nodes as shown in Eqn. 4.

$$\begin{aligned} &\mid DM(p) - DM(q) \mid > 1,\ \mu = \mu - \delta \\ &\mid DM(p) - DM(q) \mid < 1,\ \mu = \mu + \delta \\ &\mid DM(p) - DM(q) \mid == 0,\ \mu \end{aligned} \tag{4}$$

The difference of the density metric of the two nodes p and its neighbor q indicates the difference in densities in the 2-hop neighborhood. If the difference of the DM values are larger than 1 then it reveals that the neighborhood is denser; a value less than 1 indicates a non-dense neighborhood. Accordingly, the value of μ is decremented or incremented by δ = 1 or 2 and this effects the random walk length. Indeed, the value of μ is adaptively modified based on a 3-hop neighborhood density scheme.

Our proposed protocol is different from Proliferation Routing, as it considers an adaptive density metric which differentiates the density of nodes in different areas of the network. The value of μ is important in reducing or increasing the message complexity $\Theta(m)$. A low value of μ is be required in a sparse network to allow more replications of packets. The disparate routing paths produced due to the random walks largely aids in evenly distributing the node energy consumption, specific nodes are not overloaded.

In Proliferation Routing a fixed random walk step value (μ = 4) is used based on their analysis using a moderate node density of d = 9. This is not optimal in all situations since it might not be enough to alleviate radio interference and also energy consumption.

4.3 Packet Replicator

At the end of a packets life span (β = 0), its arrives at a $replicator$ node which sents a copy of the data packet to π random neighbors. The appropriate values of π and β are obtained from their relation between the end-to-end success rate (s) and path length from Proliferation routing i.e.,

$$s(1) = \binom{\pi}{n}(\rho^{\beta})^{n}(1-\rho^{\beta})^{\pi-n} \tag{5}$$

where, s is the end-to-end transmission success rate for one period of transmission, for a given n replicated packets, $n \leq \pi$. Proliferation routing consider a simplified model that all links have a fixed success rate ρ. Based on their analysis the value of π and β are set to 3 and 8 respectively and relevant values can also be obtained for different environments form Eqn. 5. The value of π should not change excessively for either dense or a sparse region in the network, values of 3 or 4 for π and double the value of μ for the β value are ideal; for most cases higher values lead to severe inefficiency with respect to the algorithms message complexity $\Theta(m)$. It will be more prudent to use the spatial diversity of the network and spread the packets modifying the length of random walks rather that increase the π value.

The individual random walk step value (μ) for each of the π random neighbors which are to enter the disseminator phase are computed in the replicator node according to the neighborhood density scheme as shown in Algorithm 1.

5. PERFORMANCE EVALUATION

To evaluate the proposed protocol, we carried out a study using the ns-2 [20] simulator. The proposed protocol Reliable Adaptive Replication Routing is compared with Proliferation Routing and a loss aware metric ETX [21] with local retransmissions; we refer to this scheme as 'ETX+RETRY'. The ETX of a link is the predicted number of data transmissions required to send a packet over that link, including retransmissions. The ETX of a link is calculated using the forward and reverse delivery ratios of the link ($ETX = 1/(prr_f \times prr_r)$). The simulation configuration consists of 500 nodes located in a 500 m^2 area with a nonuniform density; nodes are randomly distributed according to Fig. 2. A comparison of (i) End-to-End transmission success rate (S%) defined as the ratio of

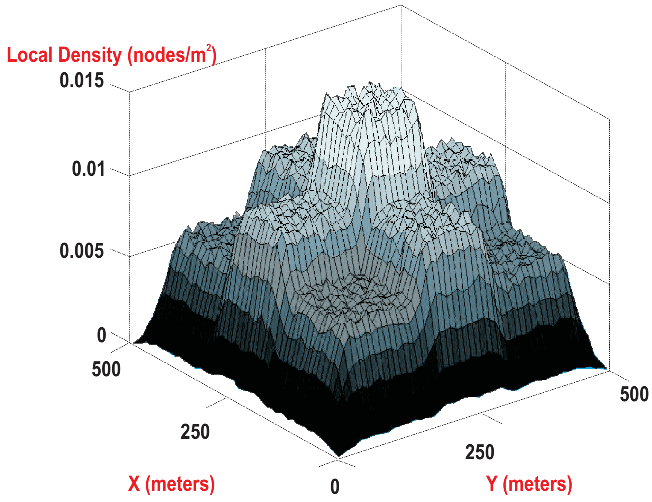

Fig. 2. Nonuniform network density

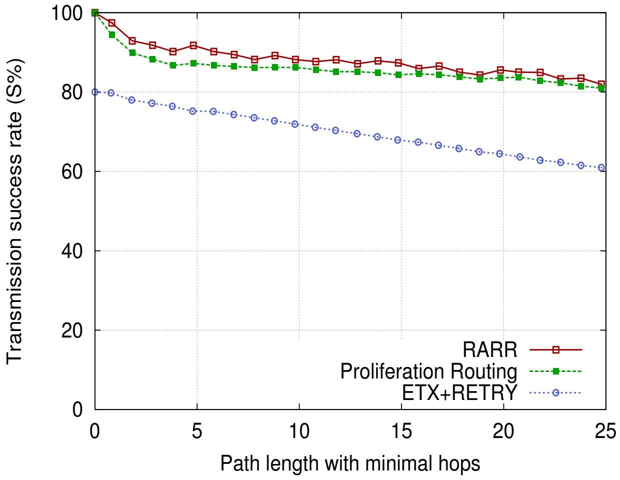

Fig. 3. Comparisons of E2E success rate for RARR, Proliferation Routing and ETX+RETRY

the successfully delivered packets to the total number of packets (ii) energy efficiency (EF %) is the ratio of the success rate and the energy cost scaled by the minimum number of hops from the node to the sink are evaluated.

$$EF = \frac{S \times hop}{\alpha} \times 100\% \tag{6}$$

Here, α is the communication overhead i.e., the total number of transmitted packets summed from all nodes in the network, that includes both sending and forwarded packets.
The transmission power for each sensor node is fixed at the beginning of the simulation to 40 meters for the nonuniform network topology. Further, to study the performance of RARR and Proliferation routing in sparse networks we consider a uniform network topology of degree set to 3 and 7 for the different simulations. In

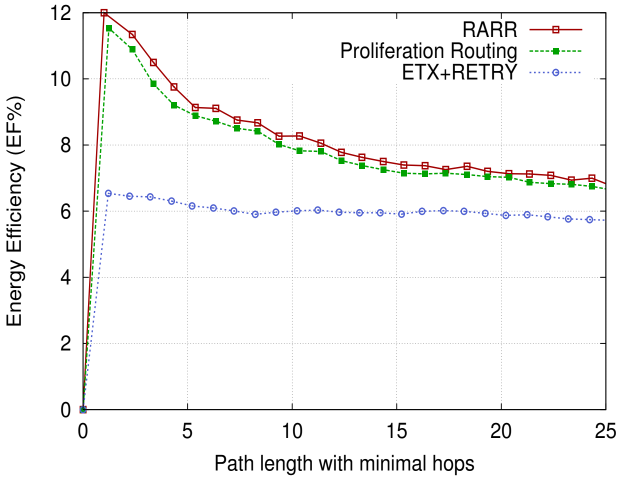

Fig. 4. Comparisons of Energy Efficiency for RARR, Proliferation Routing and ETX+RETRY

the first set of evaluations, we assume that the required end-to-end transmission success rate is 80%, according to this rate the the value of π = 3 and β = 8 are obtained form Eqn. 5 respectively. In RARR the value of μ (random walk steps) is calculated in a runtime fashion unlike Proliferation Routing. The length of path with the minimal number of hops ranges from 0 to 25.
Fig. 3 illustrates the efficiency of the RARR algorithm in improving the end-to-end transmission success rate. The ETX+RETRY technique employs the links of better quality during the routing process; however, in the denser regions of the network, the local retransmissions will have a negative effect on the E2E success rate due to the associated collisions and performs inadequately. RARR and Proliferation Routing use the packet disseminator and packet replicator to spread the packets in the topology in a controlled manner and hence achieve high end-to-end transmission success rates. RARR will adjust the random walk step value as per the varying network density and sustains the E2E success rate in the sparse regions of the topology. It can be seem from Fig. 3 the performance of RARR and Proliferation routing are similar in some regions, due to identical values of μ in certain regions of the network. From Eqn. 6 it is clear the energy efficiency of RARR and Proliferation Routing are proportional to the E2E transmission success rate (S). In ETX+RETRY has a marked lower energy efficiency, due to the flexible paths employed during the transmission. From Figure 4. initially, when the path lengths are short, RARR and Proliferation Routing have reasonable good energy efficiency; eventually, as the density of the network varies, RARR performs better. Failure of a packet in the disseminator and packet replicator phases do not trigger further retransmissions; these failed paths are not utilized again. In RARR, the disseminator takes advantage of the spatial diversity of the network and spreads the packets by modifying the length of random walks based on the neighborhood size and prevents hot stops in the network.
RARR is able to maintain a steady transmission E2E success rate by reducing the collisions and congestion and thus instrumental in improving the reliability in Wireless Sensor Networks. Although, RARR is able to uniformly balance the load among the nodes of the network, the energy efficiency need to be better.

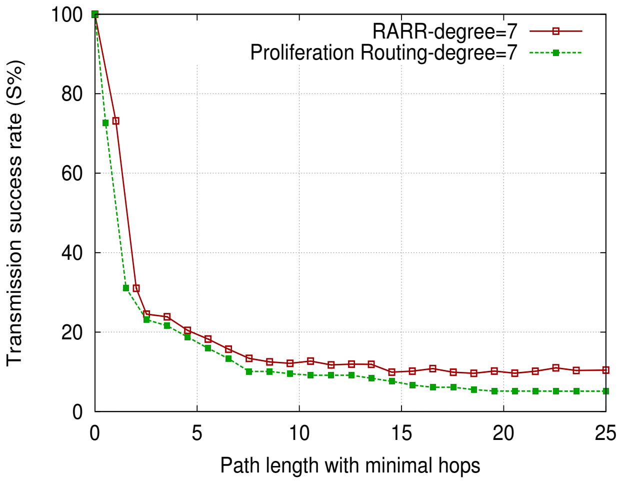

Fig. 5. Success rate S of RARR and Proliferation Routing with node degree = 7 and π = 4

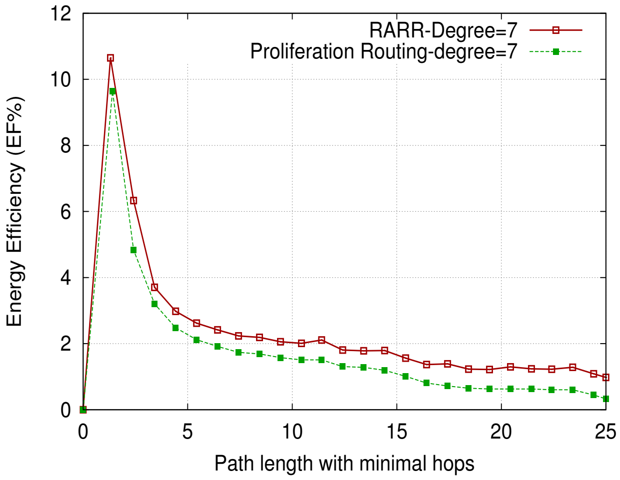

Fig. 6. Energy Efficiency of RARR and Proliferation Routing with node degree = 7 and π = 4

Additionally, we examine the performance of RARR and Proliferation Routing protocols under a sparse uniform network with node degrees of 3 and 7 respectively. The required end-to-end success rate is set to 80%, the value of $\pi = 4$ and $\beta = 8$ are obtained form Eqn. 5 respectively.

This study is important because in a network of low network density, there are lower number of links and the chance in finding a node with high link quality is low. The link capacity estimator is not be able to find paths of satisfactory reliability, resulting a lower E2E delivery ratio. The role of the disseminator becomes significant in this condition; and is done by reducing the value of μ and β to increase the frequency of replications. Fig. 5 and Fig. 6 examine the end-to-end transmission success rate and energy efficiency of both the protocols when the node degree is set to 7. Initially when the path lengths are short the end-to-end success rate is high, and drops to 30% for higher path lengths. The performance of RARR gradually improves as the path length increases and the performance is good when the path length is large. The performance of RARR gradually improves and is stable when the path lengths are large. In RARR, the stable E2E success rate is mainly due to reduction of the random walk step value and the life span of the disseminator phase resulting in more data replications. Proliferation Routing continues using the large random walk step value and incurs loss of data packets on long data paths and performs badly.

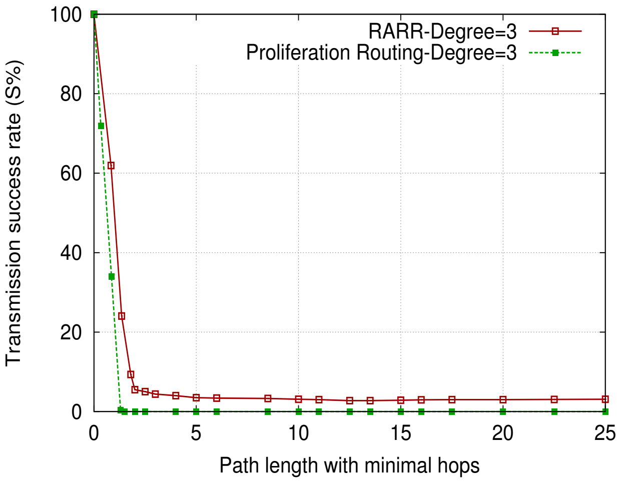

Fig. 7. Success rate S of RARR and Proliferation Routing with node degree = 3 and π = 4

From Fig. 6, energy efficiency of RARR and Proliferation Routing are high at the beginning and become stable after path lengths get longer, RARR performs better that Proliferation Routing for higher path lengths as more packets are successfully delivered to the destination.

Fig. 7 and Fig. 8 examine the end-to-end success rate and energy efficiency of both the protocols when the node degree is set to 3. In Proliferation Routing, after a brief high the end-to-end transmission success rate converges to zero and it faces the die out problem. RARR is able to sustain the end-to-end transmission success rate to about 5% better end-to-end transmission success rate for all data path lengths than Proliferation Routing which has a zero success rate for almost the entire duration of the simulation.

The results obtained highlight the fact that by dynamic adjustment of the μ and β system parameters, and retaining a constant $\pi = 3$ value for high or low densities results in higher end-to-end transmission success rate and energy efficiency.

6. CONCLUSIONS

We propose a Reliable Adaptive Replication Routing (RARR) algorithm in this paper. The algorithm employs an adaptive neighbor knowledge scheme to differentiate the density of nodes in the deployed scenario and hence reduces the collision, congestion and interference. Simulation results show that a steady success rate can be maintained in an energy-efficient way in any non-uniformly populated network compared with the traditional approaches. Future work can be carried out to further the energy efficiency.

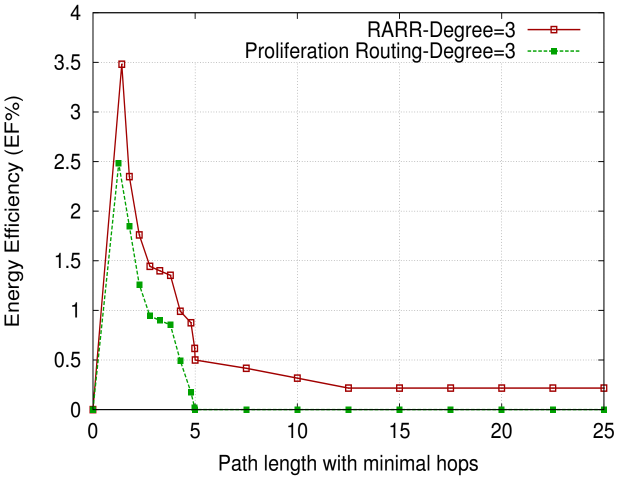

Fig. 8. Energy Efficiency of RARR and Proliferation Routing with node degree = 3 and $\pi = 4$

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