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RPRDC: Reliable Proliferation Routing with low Duty-Cycle in Wireless Sensor Networks

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Abstract

Ensuring reliable energy efficient data communication in resource constrained Wireless Sensor Networks (WSNs) is of primary concern. Traditionally, two types of re-transmission have been proposed for the data-loss, namely, End-to-End loss recovery (E2E) and per hop. In these mechanisms, lost packets are re-transmitted from a source node or an intermediate node with a low success rate. The proliferation routing[1] for QoS provisioning in WSNs low End-to-End reliability, not energy efficient and works only for transmissions from sensors to sink. This paper proposes a Reliable Proliferation Routing with low Duty Cycle [RPRDC] in WSNs that integrates three core concepts namely, (i) reliable path finder, (ii) a randomized dispersity, and (iii) forwarding. Simulation results demonstrates that packet successful delivery rate can be maintained upto 93% in RPRDC and outperform Proliferation Routing[1].

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Keywords: Reliability; Proliferation routing; Reliable path finder; End-to-End recovery; Randomized disparity.

1. Introduction

A Wireless Sensor Network (WSNs) is a group of economical sensor nodes randomly dispersed in area. The sensor node senses the ongoing events, generates and transmits packets to the sink node *via* wireless communication. The programming, re-tasking for the sensor node, command, query response from sensor nodes to sink node should be delivered reliably. Therefore, the reliability timeliness, and energy efficiency of data forwarding are crucial to ensure proper functioning of WSNs.

Recent research works focuses on two categories: (i) Packet-loss avoidance and (ii) Packet-loss recovery. The Packet-loss avoidance method is applied to minimize the packet loss and the Packet-loss recovery scheme is used to recover the packet loss. These mechanisms can be performed at each node or End-to-End.

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Motivation: Most applications in Wireless Sensor Networks, either critical or non-critical, want data without loss from sensor nodes. It is required to design communications and networking schemes which uses limited energy resources, providing reliable data transmission and satisfying End-to-End delay of critical applications without harming the network connectivity or packet loss. In this backdrop, it is challenging to design a reliable, energy efficient and low packet drop WSNs.

Contribution: (i) The issue of reliable End-to-End routing in WSNs is addressed in this work. A novel, Reliable Proliferation Routing Protocol with low Duty-Cycle is designed to overcome the End-to-End and per hop recovery schemes. (ii) A mathematical model has been developed for energy availability, link and network reliability. Energy consumption has been reduced in sensor nodes and forwarding nodes to improve the life time in WSNs.

Organisation: The paper is organized as follows: A brief review of Literature Survey is discussed in Section 2 and Background is explained in Section 3. Problem definition and Mathematical model are presented in Section 4. Reliable Proliferation routing with low duty cycle is described in Section 5. Simulation and Performance analysis are presented in Section 6 and Section 7 respectively. Section 8 contains Conclusions.

2. Literature Survey

This section, presents the state of the research highlighting the QoS issues in WSNs. Stankovic *et al.*,[2] have designed SPEED *(Stateless Protocol for Real-time Communication in Sensor Networks)* to provide soft End-to-End deadline guarantees for real-time packets in WSNs. The major limitations of the SPEED is it does not employ any packet differentiation mechanism. It gives the same preference to both real time and non-real time packets. Felemban *et al.*,[3] have presented MMSPEED (Multi-Path and Multi-SPEED Routing) protocol, an extension of the SPEED protocol to support different delivery SPEEDS[2] and different reliability. However, energy metric is not taken into account while enhancing sensor network lifetime. Hind *et al.*,[4] have proposed a protocol called *MQoSR: A Multi-objective QoS oriented routing protocol for WSNs*. Routing protocol is applied on link and path-based metrics. However, this protocol does not address prioritized scheduling with respect to application requirements.

Jie *et al.*,[5] have studied *Chain-topology in WSNs* using multiple-sending scheme for obtaining reliability between neighbor nodes. Korkmaz *et al.*,[6] have investigated link-level re-transmission and multi-path routing to enhance the reliability of Wireless Sensor Networks, However, the impact of environment on link reliability between nodes is not involved. Chao *et al.*,[7] have designed the clustering algorithm to address the predicting network lifetime using energy consumption analysis. This model does not correlate between the data transmission and energy consumption. Xu *et al.*,[8] have addressed *The Reliability Lifetime and Energy Constraint* by combining different matrices into a single objective distributed algorithm. The constraint is that the formulation of the rate reliability.

Liu *et al.*,[9] proposed a *General Failure Model* to assess the reliability of wireless mesh networks affected from a region failure. The general reliability evaluation methods are not applicable for irreparable and energy constraint nodes in WSNs. Cheng *et al.*,[10] have discussed the need of link bandwidth which makes a routing solution feasible, and provides *Mathematical Optimization Models* to tackle both energy and bandwidth constraints. The work does not address End-to-End delay. Wang *et al.*,[11] have presented *Reliability Analysis for Data Flow in Event-driven static node WSNs* to investigate wireless link reliability, network reliability, energy availability, and meantime to failure. Chen *et al.*,[12] have used cross-layer design in WSNs for Network Utility Maximization(NUM). However, they did not taken reliable packet delivery requirement, and assumed an error-free physical layer.

Abdulla *et al.*,[13] have proposed *HYbrid Multi-hop routiNg (HYMN) algorithm*, that prolong the lifetime of severely resource constrained sensor nodes. However, higher data rate leads to greater sensing and communication costs in WSNs, resulting in high energy consumption and short network lifetime. Johnson *et al.*,[14] proposed *Dynamic Source Routing protocol* that maintains routing information. If no path exists for sink again, a route discovery phase is called, which leads to significant delay in a sensor network. Stojmenovic *et al.*,[15] have proposed acyclic delivery of the packets in a non collision network. However, this protocol does not consider End-to-End delay and energy consumption. Douglas *et al.*,[16] have proposed expected transmission count metric (ETX) that determines the required number of transmissions and re-transmissions for delivering of a packet to destination. However, this metric still fails to determine the loss ratios of packet with different sizes. Fan *et al.*,[17] presented GRAdient Broadcast [GRAB] protocol which forwards packet over multiple paths instead of single paths to improve the reliability. The multipath involves large number of sensor nodes which leads to high consumption of energy.

3. Background

Liu *et al.*,[1] have identified three challenges for reliable transmission: long transmission path, radio interference resulting in packet collisions and bad link propagation. To address these issues, the authors have proposed a novel routing service called *In-middle recovery*. This method recovers packet loss in several hops rather than per-hop. Link quality information such as the Packet Reception Rate (PRR) and Reliability based path finder in proliferation routing are used to provide a reliable transmission service in WSNs. Its main task is to find more productive routing paths. The In-middle recovery scheme does not calculate link reliability between nodes, energy availability at the source node and the forwarding nodes. Nodes are not duty-cycled. The neighbor nodes are chosen randomly and the direction of the node is not always towards the sink. Moreover, this scheme works only for transmission from sensors to sink.

4. Problem Definition

Wireless Sensor nodes are energy constraint with the limited computation power and memory. It is assumed that the sink node have enough energy. The sensor nodes periodically sense data and transmit them towards the Sink(s), possibly over multiple hops. All the N sensor nodes are low duty cycle enabled (i.e. switching between active and dormant states). The nodes are differentiated into two groups, such as, sensor and forwarding nodes. The forwarding nodes can generate data as well as forward data.

The WSNs are modeled as a connectivity graph G with V nodes and L links $G(V, L)$ where $V = S \cup N$ includes both the sensor nodes and the destination, the sensor nodes are of same kind and has same transmission range, and they consume 25.5 mJ energy required to transmit data at any time. A sensor node determines its available energy level, as well as packet reception ratio between itself and its neighbor nodes in terms of delay and link reliability. Signal-to-noise ratio (SNR) indicates Link quality. The objective of the work is to design and implement reliable proliferation routing scheme with low duty cycle and determines the routing path from the source to the destination that should satisfy the following function:

$$Z : \min(f_E), \min(f_D), \max(f_R)$$

Subject to

$$\text{Min} \sum f_E f_D \leq D_{\text{req}} f_R \geq R_{\text{req}} \tag{1}$$

The objective function is to reduce energy in order to enhance the network lifetime, optimizing the End-to-End delay while maximizing the packet reliability. Thus, the first term f_E in the objective function indicates the energy utilized, the second term f_D indicates the End-to-End delay, while the third term f_R indicates the required reliability.

5. Mathematical Model

(I) *Energy consumption in a sensor node*: is categorized into (i) Energy utilization during sensing events, (ii) Energy utilization during receiving packets and (iii) Energy utilization during transmitting packets. Our objective to is to prolong the lifetime of the WSNs, where the sensor nodes can be in two states. One is the *active mode* where energy-consumption is more. While the sensor node is *active state* it performs transmission or receiving packets. The other is of a *dormant mode* where the energy is saved. The sensor node is waiting for the arrival of the next event and consumes negligible energy. Hence, the energy consumption for sensing events for the node n at time t is given by:

$$E_n^s = e_n^s(t)\ \forall n \in 1, 2, \ldots, n \tag{2}$$

Energy consumed for transmitting one packet can be defined as:

$$E_n^{tr} = \left(\frac{e_n^{el} + e_n^{tr}}{r}\right) \forall n \in 1, 2, \ldots, n \tag{3}$$

Energy required for receiving one packet can be defined as:

$$E_n^{re} = \left(\frac{e_n^{el}}{r}\right) \forall n \in 1, 2, \ldots, n \tag{4}$$

Both source nodes and forwarding nodes can sense and generate packets. Let $M_n(t)$ indicate the number of packets generated by the node n, during $(0, t)$, the $M_n(t)$ satisfies non-homogeneous poisson process with intensity function $\lambda_n(t)$.

$$E_n^{re}(t) = e_n^i - e^s(t)_n - e_n^{re} - e_n^{tr} * M_n(t) \tag{5}$$

Forwarding node residual energy: The energy consumption in forwarding nodes includes energy for receiving and re-transmitting the packets of previous nodes and the energy for sensing and transmitting the locally generated packets. Thus, residual energy of forwarding node is as follows:

$$E_n^{re}(t) = e_n^i - e^s(t)_n - (e_n^{re} + e_n^{tr})N_n(t) - e_n^{tr} M_n(t) \tag{6}$$

where $N_n(t)$ is Number of packets received from other nodes at the node n during $(0, t)$ interval. Thus, the forwarding node n residual energy at time t can be defined as:

$$P_r\{A_n\} = P_r[E_n^{re} \geq f_E] \tag{7}$$

The forwarding nodes should have greater energy than minimum energy (f_E) to meet the objective function.

(II) *Delay Estimation*: Packet delay from node i to forwarding node j is expressed as:

$$d(i, j) = d_m + d_t;\ \text{where } d_t = d_q + d_c + d_{tr}. \tag{8}$$

Total transmission delay d_t includes Queuing delay d_q, Contention delay d_c and packet transmission delay d_{tr}. Updated packet delay at the time $(t + 1)$ is obtained using Window Mean with Exponentially Weighted Moving Average (WMEWMA)

$$d_{(t+1)}(i, j) = \alpha d_{(t)}(i, j) + \frac{(1-\alpha)}{T}\left(t_{\text{ack}} - \frac{\text{Size (Ack)}}{BW} - t_s\right) \tag{9}$$

Thus, packet delay $d_{(t+1)}(i, j)$ should be less than the f_D to achieve the objective function.

(III) *Reliability Analysis*: Packets are transmitted over wireless channel. Success probability[11] between node n to node $n + 1$ is expressed as:

$$P_n^{\text{succ}} = \Phi(\sqrt{2\Psi_n}) \tag{10}$$

$$\Phi(x) = \frac{a}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{t^2}{2}\right) dt$$

Thus, probability of delivering the packets between the node i and node j is $(P^{\text{succ}}) \geq f_R$ meets the objective function. The sensor node, before transmitting a packet calculates reliability (PRRvalue). The destination node determines running average reliability. If the current reliability satisfies the required reliability, energy consumption is under control. The required reliability level is determined by the application.

As the reliability increases, End-to-End delay also increases as the packets are routed through more number of hops. Hence to meet the objective function, it is necessary to control the reliability variables to achieve energy efficiency and optimum End-to-End delay. To reduce delay, the packets are to be routed through delay efficient links.

Function: Neighbors Discovery and Link Quality Estimation
Data: Nodes in the network N
Result: Packet Reception Ratio, Link quality, Neighbors
Initialization: Node ID, Known Neighbors
while *(Until Neighbor Nodes Exists)* **do**
  if *(Passive Link-monitoring)* **then**
    Listen to the transmitted packets; Listen, even if packets are not addressed to it;
  end
  if *(Active Link-monitoring)* **then**
    Send Probe Packets to its neighbor;
  end
  if *(X receives packet M from Y at least once)* **then**
    Extractelds (Timestamp, RSSI, LQI, Seq. No);
  else
  end
  Extractelds (Timestamp, Seq.No, Retrcount) ;
end

Function 1. Neighbors discovery and link quality estimation

6. Proposed Algorithm

Function 1 determines the neighbor nodes and link quality between the nodes. The process involves three steps:

(i) *Link Monitoring*: There are two kinds of link monitoring: (a) Active link monitoring, (b) Passive link monitoring. In Active link monitoring, a node monitors the links of its neighbors by sending probe packets and in Passive link monitoring, a node listens to transmitted packets, even if these packets are not addressed to it.

(ii) *Link Measurements*: They are performed by retrieving useful information either from received packets or from sent packets. Data retrieved from received packets, such as sequence numbers, time stamp, RSSI (Received Signal Strength Indicator), and LQI (Link Quality Indicator), is used to compute receiver-side link quality estimators. On the other hand, data retrieved from sent packets, e.g., sequence numbers, time stamp and packet re-transmission count, allows for the computation of sender-side link quality estimators.

(iii) *Metric Evaluation*: It is based on link measurements, a metric is evaluated to produce an estimation of the link quality.

Function: Nodes direction( )
Step 1: Start
Step 2: Input Node, message; Initialize Node *ID*, Parent node
Step 3: **While**(Parent node is not connected to sink) **do**
Step 4: Node *a* sends *Forward* message to *p(a)* set timeout
Step 5: **If**(*p(a)* connected to sink)
Step 6 Send *BackY* message and No. of hops to sink
  else
Step 7: Send *BackN* message to Node *a*
  EndIf
  End While
Step 8: Output No. of Hops to Sink Node
Step 9: Stop

Function: Reliability Path Finder $\delta()$
Step 1: Start
Step 2: *Determine* packet reception ratio using The Window Mean with Exponentially Weighted Moving Average (WMEWMA), where, r is the number of packets received, m is the number of packets missed and $\alpha \epsilon$ [0,1] controls the smoothness.
$\mathrm{Prr}_{(i,j)} = \alpha * \mathrm{Prr}_{(i,j)} + (1-\alpha) * \frac{r}{(r+m)}$
Step 3: Determine link asymmetry by taking the difference between the *PRRup* and the *PRRdown* ASL(w) $= \mathrm{Prr}_{\mathrm{up}} - \mathrm{Prr}_{\mathrm{down}}$
Step 4: Stability of link basically computed based on a past record of 30 $\mathrm{Prr}_{(i,j)}$, $\mathrm{Prr}_{(j,i)}$
Step 5: *Compute* channel quality through the measure of the Signal-to-Noise Ratio(SNR). Sampling RSSI at Packet reception.
Step 6: *Compute* forwarding node residual energy at each node
Energy consumption includes the energy for receiving and re-transmitting packets of previous nodes and the energy for sensing events and transmitting the locally generated packets.
Step 7: Output Forwarding node
Step 8: Stop

After a sensor node has been identified from the set of sensor nodes in the direction of destination using function Nodes direction( ) it randomly picks up a neighbor that continues to relay the packet it has received. This is to fully exploit the spatial diversity and reduce the risk of radio interference. In each packet, there is *TTLrandom* number and *TTLfield*. *TTLrandom* initial value is set by the source node to control the total number of randomized forwarding nodes. If *TTLrandom* is greater than zero it then selects the random neighbor to forward the packet after a certain

Data: Packets, Nodes, Sink, Neighbor nodes
Result: Reliable Routing path from Source to Sink
Initialization: Nodes in active state, Node Energy;
while *(Until Routing path does not exist)* **do**
    Node in active state, Duty-cycled;
    N(u), LQI = *Neighbors Discovery and Link Quality Estimation ( );* Exchange 2 hop neighbors
    if *(Recvd.pkt* ***pr*** *|| Sensed.pkt* ***ps*** *and Active)* **then**
        Extract TTL value from packet **pr**|| **ps**; Set TTL=TTL-1;
        if *(TTL ≥ 0)* **then**
            Extract TTL_{rand} value from packet; Decrement TTL_{rand} by 1
            if *(TTLrand ≥ 0)* **then**
                No. of Hops =*Nodes direction( );* Select Random neighbor as a forwarder
            end
            else
                No. of Hops =*Nodes direction( );* Forwarder (ω)=Reliability Path Finder( );
            end
        end
        else
            Packets triggers forwarding phase; Compute: Random walk ω; Set $\mathrm{TTL}_{rand} = \omega$; γ: Hop-distance between 2 adjacent reproducer
            τ : No. of packets produced; Set TTL = γ; Transmit the packets to τ random neighbor
            No. of Hops =*Nodes direction( );* ; Check Node State (Active or Dormant and Duty-cycle)
        end
    end
    else
        Node is in passive state
    end
end
end

Algorithm 2. RPRDC: Reliable Proliferation Routing Duty-Cycle random walk as controlled by *TTLrandom*, the packet then enters into the deterministic phase where the packets follow the reliability-based path finder (function Reliability Path Finder ( )). If TTL_{random} is zero, then random neighbor using reliability path finder is selected.

Estimation of Reliability of Relay Node: Every relay node maintains a reliability value that reflects the estimated transmission success rate from the node to the next node. The forwarding node is selected if and if only it satisfies following: If the link has better packet reception ratio AND low unevenness AND immense stability AND immense channel quality AND higher residual energy then it has high reliability.

Estimation of Energy Availability at Forwarding Node: For forwarding nodes, the energy consumption includes the energy for receiving and re-transmitting packets of previous nodes and the energy for sensing events and transmitting the locally generated packets. After each forwarding, the TTL field is reduced by 1. When the TTL count reaches 0, the final node receiving this packet stops the random propagation phase. It reproduces several new packets to compensate those lost ones. Because, some packets may fail during transmission. The number of hops that a packet needs to traverse before forwarding is called packet lifetime and the node involved in forwarding packets is called forwarder nodes. Transmissions from one forwarder to the next one is called *life cycle*.

ACK Packets from Selected Random Neighbor to Sender: A data packet can be reliably sent with link-layer acknowledgements from neighbor node to sender. Link-layer acknowledgements thus have an advantage over no-acknowledgements or only End-to-End acknowledgements because only local node is involved in the re-transmission and thus fewer data packets are re-transmitted due to failed acknowledgement packets.

Forwarding Phase: When TTL value (time-to-live) in packet is zero then the forwarding node reproduces the packet to continue the journey towards the destination. The number of the reproduced packets in each forwarding is called the forwarding coefficient γ . The node receiving such packets then becomes a seed reproducer and begins the forwarding.

7. Simulation Set-up

Simulation is conducted extensively using NS-2 Simulator to evaluate the performance of RPRDC algorithm. Simulations are performed on a uniform topology consisting of 50 nodes spread in the square area of 180 m*180 m. The transmission range of all nodes in 25 m, link reliability ranges from 0.8 to 1, Packet size is of 1024 bits. The delay requirement is from 120 ms to 140 ms; nascent energy of each node is set 5 J; energy consumed during transmit is 0.0255 J; energy consumed to receive packet is 0.021 J; energy consumed during sleep mode is 0.5 μJ; MAC layer protocol is 802.11 with Distributed Coordination Function (DCF). Constant Bit Rate (CBR) is application protocol.

8. Performance Analysis

End-to-End delay of each transmission ν, Energy consumed E^{tot}, Expected packet Lifetime and minimum number of hops. These are four main measurable parameters used to evaluate the effectiveness of *RPRDC* protocol. (i) *End-to-End Successful Probability of each Transmission-v:* It is the ratio of successfully delivered packets to the total number of packets generated; the success rate is the average over five independent runs. (ii) *Energy Efficiency* E^{tot}: Average energy consumed in active mode of sensor node over the simulation time. (iii) *Number of Hops Required for a Successful Packet Delivery*: Minimum number of hops required between source to destination. (iv) *Expected Packet Life-Time*: Number of hops that a packet need to traverse before forwarding.

Figure 1 depicts packet delivery ratio under different node density. Initially, when the density of nodes is low, the DSR[14] performance is good and gives the best packet delivery ratio. The algorithm SPEEDS[2], SPPEDT[2], GF[15] performs equally well as DSR. The performance of RPRDC is lower than SPEEDS, SPEEDT, DSR and GF. The performance of RPRDC is increasing linearly with the increase in node density and the packet delivery ratio rise 87% to 95%. With the further increase in node density, the packet delivery ratio in RPRDC reaches a maximum of 97%. The packet loss of 3–5% in RPRDC is due to radio interference and packet collision. Thus, RPRDC outperforms DSR,

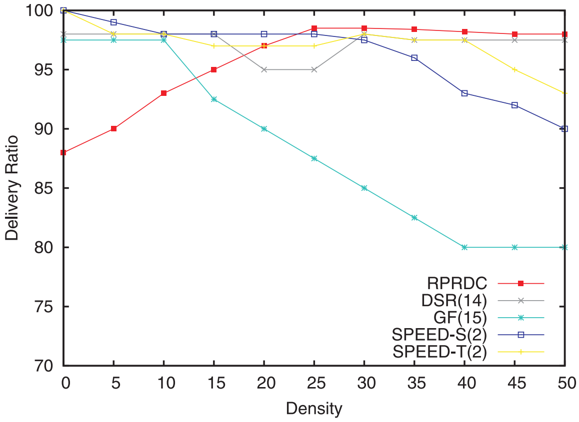

Fig. 1. End-to-End delivery ratio of routing algorithms under different node densities.

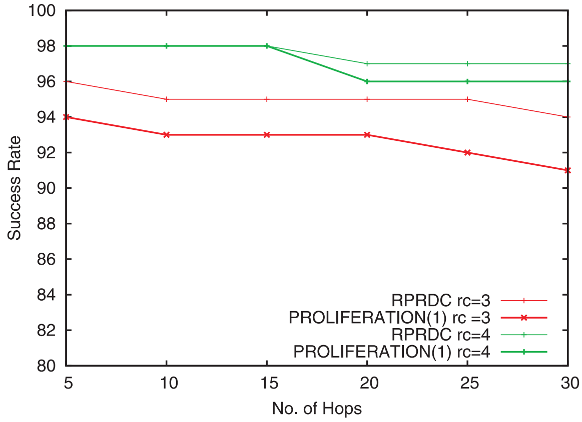

Fig. 2. No. of Hops v/s Success rate with the different value of τ, given $\lambda = 0.9$ and the packet life-time $\gamma = 5$, given $rc = 3$, $rc = 4$.

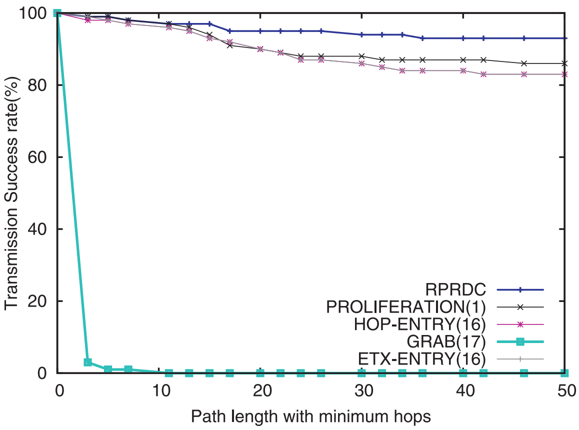

Fig. 3. Packet length v/s transmission success rate given $(\tau) = 3$ and $(\lambda) = 8$.

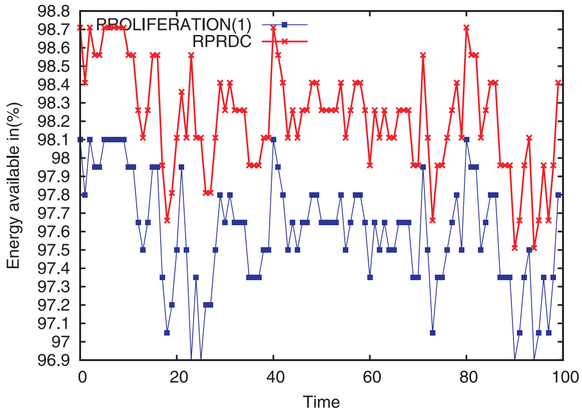

Fig. 4. Time in (secs) v/s Energy in(Js) and the Energy availability is about 98.4%.

GF, SPEEDS and SPEEDT in high density network. This is an account of choosing a energy efficient forwarder with the minimum delay and maximum reliability.

Figure 2 shows the packet success rate with the number of hops. The success of RPRDC is compared with the proliferation routing[1]. It is observed that the results are almost similar, but the performance of RPRDC is higher than proliferation routing[1] in both the cases i.e., when $rc = 3$ and $rc = 4$.

Figure 3 depicts the transmission success rate with pathlengths in minimum hops. The RPRDC protocol is compared with the existing protocols namely proliferation routing[1], Hop-Entry[16], ETX-Entry[16], GRAB[17]. The Hop-Entry protocol employs links with minimum hops while ETX-Entry empty links of higher reliability. These two protocols uses local re-transmission mechanism guaranteeing the per-hop reliability in order to achieve End-to-End delivery. Therefore, their success rate is almost the same (about 88%) for shorter and longer hops. The GRAB protocol proactive mechanism of fault tolerant is quickly offset by long transmission path and hence the success rate declines rapidly with the increase in the number of hops. The proliferation protocol achieves a maximum of 90% success rate while RPRDC protocol outperforms all the protocols mentioned above achieving a maximum transmission success rate of 93% when τ=3 and λ=8. This is due to selection of reliable path finder, energy efficient forwarder and path of minimum delay.

Figure 4 shows that the plot of available energy at the nodes in the RPRDC protocol and proliferation routing[1]. It is observed that RPRDC has higher energy availability than proliferation routing. This is due to reduced energy

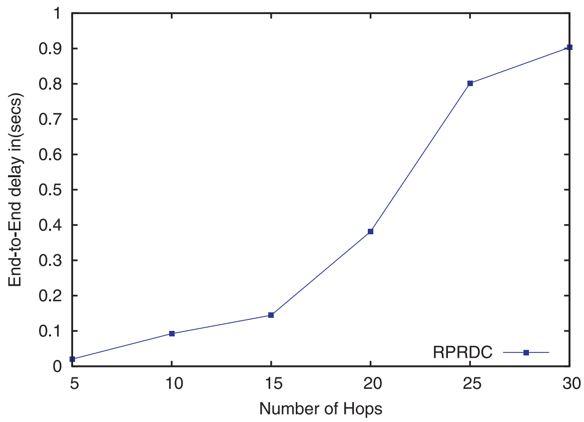

Fig. 5. Application = CBR, Simulation time = 100 seconds, Number of hops = 30 Hops.

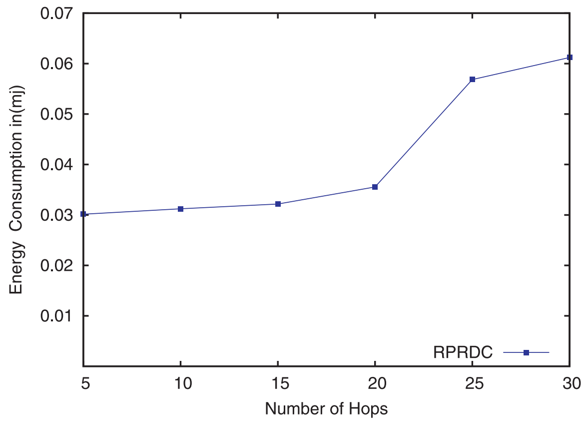

Fig. 6. Energy consumption during transmitting and receiving, Average packet rate = 0.5 packets/seconds and initial energy = 5 Joules.

consumption during transmission, receiving and sensing in RPRDC. Moreover, the sensor nodes are duty-cycled i.e, active and passive states. The combined effect of low duty-cycled and reduced transmission/receiving/sensing energy results higher energy availability in RPRDC than the proliferation routing which is not duty-cycled. The RPRDC has an average energy availability of 98.4% in comparison with the proliferation routing whose energy availability is 97.85%. Therefore, the RPRDC protocol outperforms the proliferation routing with respect to the lifetime of the WSNs.

Figure 5 plots average End-to-End delay for different number of nodes. The End-to-End delay of a packet depends on the channel access time, transmission time, waiting time and processing time at each hop. Between 15 to 25 nodes End-to-End delay increases because more number of nodes involved in accessing the channel and waiting time. There is linear a increase in the End-to-End delay when the nodes increase from 25 to 30.

Figure 6 plots energy consumption versus number of nodes in the network. The total energy consumption includes energy spent during transmission, reception, idle and sleep modes. The reliability requirement and the number of retransmissions increases with the number of hops.

9. Conclusions

The combined effect of low duty-cycled sensor nodes, reduced packet re-transmission due to the high link reliability, reduced transmission/receiving/sensing of source and forwarding nodes enables the RPRDC protocol to outperform proliferation routing[1]. Further, the RPRDC protocol maybe explored to achieve minimization objective with respect to sparse and heterogeneous WSNs.

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