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A Real-Time Routing Protocol with Controlled Dissemination of Data Queries by Mobile Sink in Wireless Sensor Networks

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Abstract

Objective: One of the challenges faced in wireless sensor networks is the constraints in battery power. The main objective of this paper is to address the energy efficiency issue by proposing a real-time routing protocol with controlled dissemination of data queries by mobile sink (RTCD). **Methodology:** Two phases namely the flooding phase and the routing phase are followed for data collection by mobile sink. A mobile sink helps in efficient data gathering compared to a static sink, reducing the total energy consumption in the network. In the flooding phase, controlled dissemination is achieved by limiting the network diameter and setting a threshold value for residual energy of the nodes. In the routing phase, routing of data is done on the basis of choosing an optimal forwarder having the maximum weighted value of composite link metric, comprising the Parameters Packet Reception rate (PRR), packet one-hop velocity and residual energy of the nodes. Real-time data delivery ensures delivery of packets within deadlines in delay- constrained applications. **Findings:** Simulations using Network Simulator-2 suggest that the routing phase in RTCD outperforms the reactive, proactive and hybrid routing protocols in terms of QoS parameters such as Packet Delivery Ratio (PDR), Normalized Energy Consumption (NEC) and average end-to-end delay. The reactive, proactive and hybrid routing protocols considered are AODV, DSDV and ZRP respectively. It has been found that PDR for RTCD routing is higher than comparative protocols for large networks. RTCD routing gives intermediate results in case of average end-to-end delay and NEC. Also, the impact of network diameter on Total Energy Consumption (TEC) has been studied which shows that TEC increases with network diameter. An optimum value of 1.8J is set as the threshold value of residual energy of nodes based on the simulation results for controlling the energy consumption.

Keywords: Controlled Dissemination, Energy Efficiency, Mobile Sink, Packet One-Hop Velocity, Packet Reception Rate, Real-Time Routing

1. Introduction

A large network of sensors together form a wireless sensor network, which are deployed in a certain area for collecting different kinds of information depending on the application. The system architecture consists of an assemblage of static nodes, a mobile sink and upper communication substructure[1,2]. The sink or base station collects information from each sensor and performs appropriate actions[3]. It is attached to an external entity like the internet and relays the information. The mobile sink can have active mobility which has motors equipped and passive mobility where sensors are attached to mobile objects. The sensor nodes form a multi-hop environment. Each sensor module consists of a sensor, a transceiver, a processor and memory and power entities. Examples of mobile sink are laptop, PDA and an Unmanned Aerial Vehicle (UAV) which travel to certain regions in the network and

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collects data. The mobile sink helps in improving scalability, maintaining load balance, conserving energy and prolonging network lifetime[1].

Like traditional networks, these networks have constraints in power, computational capacity and memory. Sensor nodes in bulk are placed randomly in a particular area in WSNs. Since the neighbor nodes stay in close proximity, multi-hop routing is the best for enabling channel reuse and overcoming signal propagation effects in a real-time scenario. Moreover, the information collected has to be delivered to mobile sink in time. Delay-constrained applications such as fire-fighting, health monitoring cause fatalities if the data is delivered any later. Thus, end-to-end delay has to be either deterministic or probabilistic for real-time support[4].

The main aim of RTCD protocol is improving network lifetime by controlling the amount of control messages spread through the network and route the data by choosing an optimal forwarder with best value of composite link metric. This paper proposes controlled flooding based scheme and goes for an optimal forwarder subjected to the parameters including packet reception rate, sensor nodes' residual energy and one-hop packet velocity. The throughput is improved since packet reception rate is considered which represents link quality. Real-time packet delivery is ensured by preferring forwarding nodes with highest possible one-hop packet velocity. Opting nodes with more unexpended battery power improves the network lifetime, where the nodes with less energy are not chosen for forwarding. The performance of the protocol is evaluated in terms of packet delivery ratio, average end-to-end delay and Normalized Energy Consumption (NEC) using Network Simulator-2 (NS2)[5].

The paper is arranged as follows: The related work on real-time routing, mobility in WSNs and existing routing protocols in wireless networks have been discussed in Section 2. Section 3 explains the algorithm and Section 4 presents the simulation results and analysis. The conclusion is provided in Section 5.

2. Related Work

Generally, routing in WSNs is classified into four kinds of routing. Depending on network structure, they can be categorized into flat-based routing (nodes have uniformity), hierarchical based routing (nodes have different functions), and location-based routing. In addition, they can be divided into proactive, reactive and hybrid routing depending on the process of route formation. Classification is also done based on operation of protocol into query-based, QoS-based, forwarding-based, negotiation-based and coherent-based routing techniques.

Mobile wireless sensor networks have gained attention during the past few years. The mobility can be active or passive depending on the application. Active mobility involves the sensors to have motors equipped to them, whereas the sensor nodes are connected to mobile devices in case of passive mobility. Examples of active mobility are underwater sensors fitted with motors for assembling data from stationary sensor nodes. Sensors attached to micro air vehicles, unmanned aerial vehicles and animals are examples of passive mobility[6]. Numerous real-time routing protocols have been developed for static as well as mobile wireless sensor networks.

RAP is a real-time communication architecture whose main idea is packet velocity scheduling[7]. Packet deadline and destination are used for calculation of velocity and priority is given to the packets in the velocity-monotonic order. Packets with higher velocity are delivered earlier than packets with lower velocity. A similar protocol SPEED, is designed for scalability in WSN for real-time[8]. It enforces uniform communication speed for each hop and limits the end-to-end delay, through feedback control together with QoS-aware geocast forwarding.

RTPC (Real-time power control) routing protocol uses energy efficiency with velocity for choosing the next-hop node for forwarding[9]. RTPC, RAP and SPEED, having the metric as velocity, do not produce high throughput. RTPC lags in delivery ratio as it uses minimum hop count also for forwarding. They are designed only for static WSNs.

RTLD is a real-time routing protocol with load distribution for WSNs[10]. Choice of optimal forwarder is calculated using packet one-hop velocity, PRR and remaining battery level of the nodes. It gives good performance with reference to control message overhead, packet delivery ratio and energy utilization. But this does not work for mobile WSNs as it depends on location management which is suitable only for static WSNs.

ERTLD is an enhanced real-time routing protocol which is an advancement over RTLD suitable for mobile WSNs. The optimal forwarding choice calculation includes RSSI, battery voltage and end-to-end delay metrics. RSSI, which is a cross-layered metric, is a real-time parameter extracted for every RTR packet and acts as a measure of link quality. It uses corona mechanism for periodic broadcast of control messages[11]. It exhibits high performance in mobile WSNs, however the broadcast storm imposes serious energy constraints. Also, the time-varying nature of RSSI may not give optimal value and nodes in transition region can significantly affect forwarding.

Hierarchical based routing includes clustering algorithms in which nodes are segregated into small groups called clusters. A cluster head is selected for each cluster and communicated by all the other nodes in the cluster for collecting data. Clustering in WSNs improves the scalability and also helps in effective utilization of resources. Examples of clustering protocols are LEACH, which is a basic clustering algorithm and its enhanced versions such as M-LEACH and V-LEACH[12]. But the disadvantages in clustering are increase of end-to-end delay with time and overhead resulting due to election of cluster head and it worsens in mobile scenarios[12, 13].

Greedy Perimeter Stateless Routing (GPSR) is the commonly used location-based protocol for mobile wireless networks. It implements Greedy forwarding method along with Perimeter forwarding[14]. In the former method, the sender selects that node as the next hop node which is the nearest to the destination geographically. In the case where an intermediate node fails to present between the source and the destination, perimeter forwarding method is employed. It is not scalable for large scale networks like WSNs.

Destination-Sequenced Distance Vector routing algorithm is a table-driven proactive routing algorithm. The prime advantage of this proactive routing is that it solves the routing loop problem. Every node maintains a routing table based on which routes are selected to the destination. DSDV is not scalable for highly dynamic networks because large amount of bandwidth is utilized in the updating process.

Ad-hoc On-demand Distance Vector routing is a reactive routing approach in MANETs, implying it needs to maintain routing information of only the active routes[15]. The routes are formed dynamically on-demand rather than maintaining routing table information as in proactive approach. When a source wants to communicate with the destination, it initiates the route discovery mechanism. It then broadcasts route request (RREQ) packets to its neighboring nodes. The drawback in this protocol is that route discovery procedure incurs more delay overhead compared to proactive routing.

Hybrid routing protocols are developed which combine the pros of both proactive and reactive protocols. One such hybrid routing protocol wherein each node defines a zone based on number of hops is the Zone Routing Protocol (ZRP)[16]. All the nodes within the hop range belong to the zone. A proactive protocol, called the Intra-zone Routing Protocol (IARP) is used inside the zone and a reactive protocol, called the Inter-zone Routing Protocol (IERP) is used outside the zone. ZRP reduces the overall control overhead due to proactive routing and delay overhead due to reactive routing and can be effectively used in large scale mobile networks such as mobile WSNs.

3. RTCD Routing Protocol

The RTCD protocol architecture consists of four modules which include controlled flooding mechanism, routing management, power management and neighborhood management as in Figure 1. The mobile sink performs controlled flooding indicating its presence in a particular location and then collects data from that area. This data is routed by the source to the sink through intermediate nodes based on maximum weighted composite link metric value calculated by the routing management. The neighborhood management maintains neighbor table of the forwarding nodes. The transmission power level and state of the node are determined by power management[10,11]. Data collection by mobile sink requires two phases 1. Flooding phase and 2. Routing phase.

3.1 Controlled Dissemination Mechanism

In the flooding phase, the sink broadcasts control messages periodically to one-hop neighbors, which they in turn broadcast to other nodes so that the messages reach

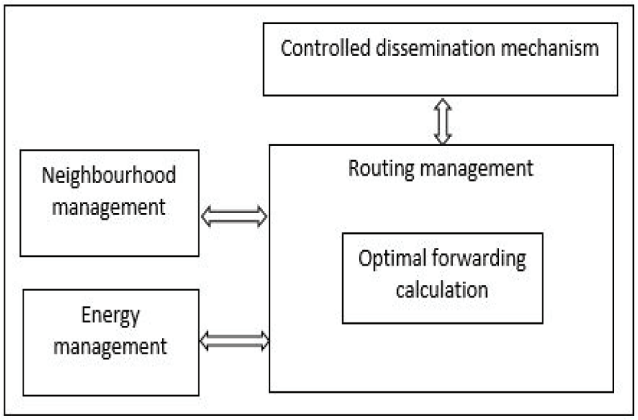
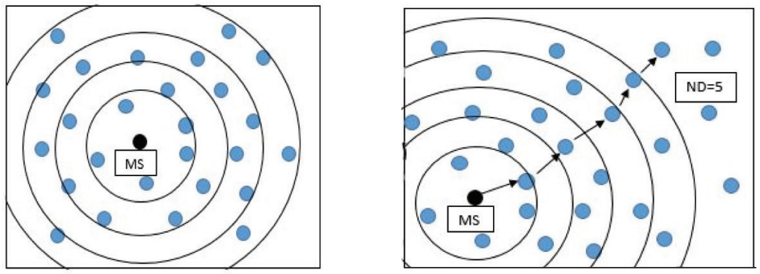


Figure 1. Block diagram of RTCD architecture.



(a) (b)

Figure 2. Illustration of controlled dissemination by Mobile Sink (MS). (a) Broadcast of control messages by MS. (b) Network Diameter (ND) set to 5.

throughout the network. The sink moves at random throughout the network at random intervals of time. It is to be noted that only the sink generates control packets. This makes sure that every node is updated periodically of the presence of the mobile sink. But this has its toll on the energy of the nodes and memory. So a controlled dissemination mechanism is proposed in which a threshold value of energy is set for each of the nodes. If the residual energy of the nodes is below this threshold value, those nodes do not participate in forwarding the control messages. In some of the applications, the nodes switch to sleep mode, which enables the recharge of their battery. By this approach, nodes which have less energy are not involved in further expending, contributing to network lifetime.

Another parameter called Network Diameter (ND) is also considered in this mechanism which is proportional to the number of hops a control packet is forwarded. If the network diameter is set to 5, the control packet broadcasted by the sink takes only 5 hops and gets dropped after 5 hops. This implies the sink floods only a limited area where it travels to and collects the data, preventing broadcast storms that lead to significant battery power consumption and possible network meltdown. The controlled dissemination mechanism is illustrated in Figure 2.

The algorithm of controlled dissemination mechanism is described in Figure 3. Taking the above mentioned parameters into account lessens the Total Energy Consumption (TEC) in the network, thereby improving network lifetime.

3.2 Routing Management

3.2.1 Composite Link Metric Calculation

In the routing phase, the weighted composite link metric for forwarding data is calculated by the source node for its one-hop neighbours considering the metrics of packet reception rate, residual energy of the node and packet one-hop velocity. The best node for forwarding is the one which has highest composite link metric.

```
Inputs: data query, mobile sink, hops=0, neighbor node,
ND, threshold value
Algorithm:
if (MS is travelling)
MS be in idle mode;
do {
MS starts broadcasting;
for all nodes receiving data query from MS
        if (number of hops <=ND) {
           if (residual energy of next hop node > threshold
         value) {
         forward data query to neighbor node;
         hops= hops+1;
                  }
       else discard data query;
        }
}while (sink remains stationary);
```

Figure 3. Controlled dissemination algorithm.

$$\text{Composite link metric} = \max\left(\alpha_1 * PRR + \alpha_2 * V/V_{max} + \alpha_3 * E_{rem}/E_{max}\right) \quad (1)$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$ and PRR is Packet Reception Rate; V is the Packet one-hop velocity between two sensors; E_{rem} is the residual energy of the neighbour node; V_{max} is the maximum packet velocity between two sensor nodes; E_{max} is the initial energy configured to nodes equal to 3.6J[17]; and $\alpha_1 = 0.6$, $\alpha_2 = 0.2$, $\alpha_3 = 0.2$ from the finding in the paper[18].

3.2.2 PRR Metric Modeling

Packet Reception Rate (PRR) between two nodes is the likeliness that a packet is received successfully. It is taken as the measure for link quality. More the PRR, higher is the link quality. The PRR metric is modelled with respect to the distance between the two nodes[19]. The PRR is 1 when the distance of separation is less than or equal to D_{cmax}.

PRR when the distance is between D_{cmax} and D_{tmax} fluctuates around the decline from connected region to transition region as in Figure 4. Reception is zero when the distance is more than D_{tmax}.

$$PRR = \begin{cases} 1, \text{ for } D_{sd} < D_{cmax} \\ (D_{tmax}-D_{sd})/(D_{tmax}-D_{cmax}), \\ \text{ for } D_{cmax} < D_{sd} < D_{tmax} \\ 0, \text{ for } D_{sd} > D_{tmax} \end{cases} \quad (2)$$

where D_{sd} is the distance between source and destination.

The nodes are configured based on the transmission power level and also the propagation environment modelled by path loss exponent and standard deviation in the log normal shadowing[20]. The transmission power level of the nodes influences D_{cmax} and D_{tmax} values. Choosing nodes with higher transmission power level minimizes the end-to-end delay, but has its effect on energy dissipation, interference and collisions. Hence best suited value of power is chosen for transmission which results in compromise between delay and total energy consumption, since the major goal is improving network lifetime.

3.2.3 Packet Velocity Metric

Packet velocity ensures real-time data delivery as the sensor closer to the destination will be chosen for forwarding. It can be defined as the ratio of progress towards the destination to the delay in reaching the next one-hop neighbor. The probability that a packet arrives at the destination before its intended time is high when packet one-hop velocity is high.

$$V = (Dsd-Dnd)/\text{Delay b/w } (S,N) \quad (3)$$

where D_{sd}- Separation between source and destination

D_{nd}- Separation between neighboring node and destination.

D_{sd}- D_{nd} = progress towards the destination.

$$\text{Delay b/w } (S,N) = T_t + T_p + T_q + T_b + T_s + T_c$$
$$= \text{Round Trip Time} / 2. \quad (4)$$

where,

Delay b/w (S,N) - total delay incurred from source S to node N by RTR packet.

Tt – Packet transmission time.

Tp- Propagation delay.

Tq- Queuing delay.

Tb- Processing delay.

Ts- Sleep to active transition delay.

Tc – Time taken to obtain channel using CSMA/CA by the source.

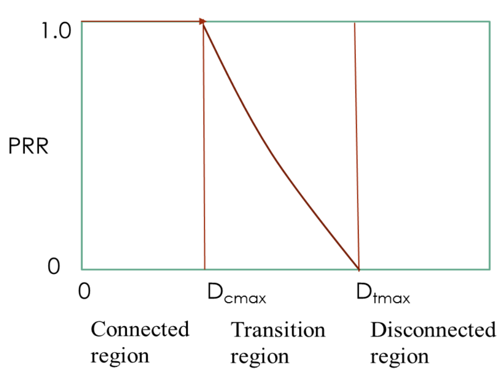


Figure 4. Approximation of PRR vs one-hop distance (m).

3.2.4 Energy Metric

Energy metric is considered to avoid routing holes and network partitions. The nodes tend to follow the same route which results in total drain out of some of the nodes in the routing path between node 0 and node 24 as depicted in Figure 5. This reduces the network lifetime.

3.2.5 Neighborhood Management

The neighbourhood management invokes the neighbour discovery mechanism when it finds the neighbour table empty. Request To Route (RTR) packets are broadcasted by the source node initially. The nodes which satisfy the

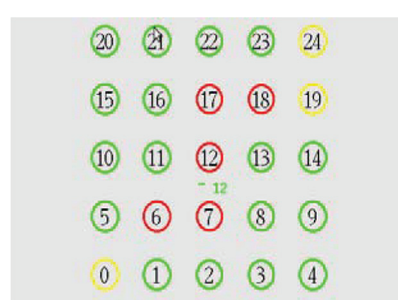


Figure 5. Network partition in 25 node grid.

forwarding condition alone reply to RTR to the source node. These nodes are included in the neighbor table. A small overhead is incurred due to neighbor discovery procedure. The number of entries in the routing table are limited due to constraints in memory. Each entry includes next hop node id, remaining energy, PRR, one-hop delay, forward flag, location information and timeout value.

3.2.6 *Energy Management*

The energy consumed by each node has to be minimized so as to prolong the network lifetime. The power level of the transceiver is adjusted and transmission power level is chosen. This lessens the energy consumed by each intermediate node between source and destination. Power management reduces the energy wastage by idle listening and control packets. The nodes which are not involved in forwarding switch from active state to idle state. The forwarding nodes are in active state during communication and return to idle state after data transfer. Thus Total Energy Consumption (TEC) is reduced.

4. Simulation Results and Analysis

A simulation study for observing the effect of varying threshold value of energy for the nodes on the total energy consumption of the network is carried out. Also, evaluation of the effect of varying network diameter for different network sizes on TEC is done. The simulations are done using the NS2 simulator with IEEE 802.15.4 MAC/PHY layers support. Table 1 shows the parameters used in simulations in NS2. Table 2 gives the parameters and their values used in log normal shadowing model.

The performance of routing phase of RTCD is evaluated by comparison with existing routing protocols AODV, DSDV and ZRP with the QoS metrics being Packet Delivery Ratio (PDR), average end to end delay (E2E delay) and Normalized Energy Consumption (NEC). Simulations are done in a grid scenario of 25 static nodes as in Figure 6 with source and sink being on either end of the diagonal.

4.1 Evaluation of the Metrics PRR, Packet One-Hop Velocity and Energy w.r.t. PDR, E2E Delay and NEC

The individual metrics PRR, packet one-hop velocity and remaining energy (Er) have been compared to the composite link metric and analyzed with respect to the metrics PDR, average end-to-end delay and NEC. Figure 7 shows the PDR comparison for the above considered metrics. It can be observed that nodes having maximum PRR has higher PDR because the neighbor lies within the connected region, ignoring the number of hops The max velocity metric has lower PDR as it attempts to minimize the hop count and choose maximum progress providing lesser delay, ignoring the link quality issue. The composite link metric gives higher

Table 1. Simulation parameters

Parameter	Value
phyType	Phy/WirelessPhy/802_15_4
macType	Mac/802_15_4
Transport layer	UDP
Traffic type	CBR
Frequency	2.4 GHz
Initial energy	3.6 J
Propagation model	Shadowing
Packet rate	5 packets/sec
Simulation time	150sec, 500 sec
Receiving rate	90%
No of nodes	9, 25, 49

Table 2. Shadowing model parameters

Parameter	Value
Path Loss Exponent	2.7
Shadowing deviation (dB)	4.0
Reference distance (m)	1.0

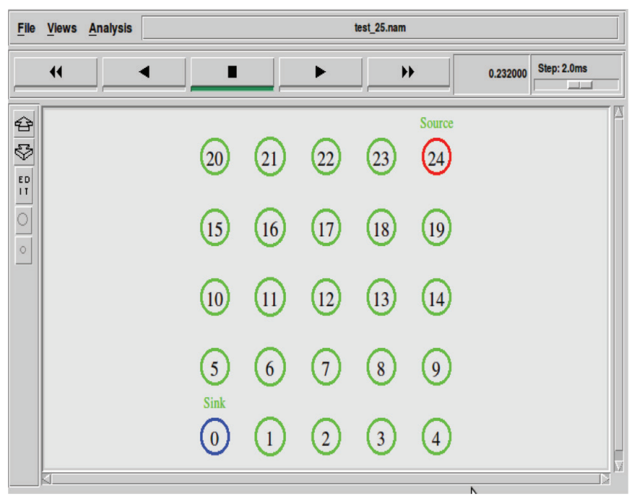


Figure 6. Network of 25 nodes grid in Network Animator.

PDR as it minimizes the number of hops while considering link quality at the same time.

The impact on average end-to-end delay can be observed from the Figure 8. Nodes with max PRR has higher end-to-end delay as it focuses only on link quality and not on the number of hops. Max velocity metric gives lesser end-to-end delay as it takes minimum number of hops to get to the sink. The composite link metric gives optimal delay as the number of hops are minimized while considering link quality at the same time.

The impact of various metrics on NEC is shown in the Figure 9. Nodes with max remaining energy (Er) consume more energy as the nodes with more energy are chosen for forwarding. Nodes with max PRR also show significant NEC as more nodes are required for forwarding information to the sink. The composite link metric shows relatively lower energy consumption as hops are minimized and good link quality nodes are chosen.

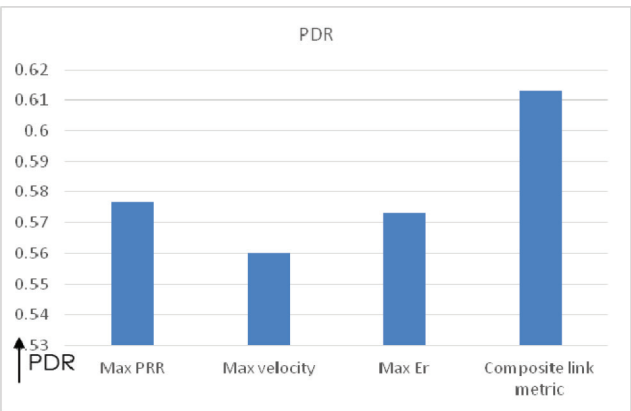


Figure 7. PDR comparison for standalone and composite metrics.

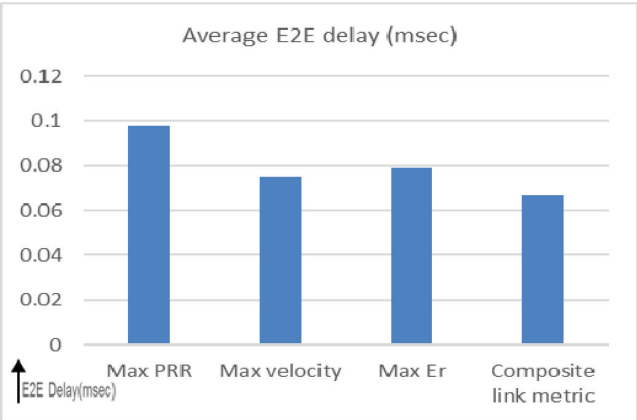


Figure 8. Average E2E delay comparison for standalone and composite metrics.

4.2 Variation of Total Energy Consumption (TEC) with Threshold Value of Energy of Nodes

The Total Energy Consumption (TEC) by the network is the aggregate of the individual energies expended by all the nodes inthe network. As depicted in Figure 3, a node checks if the next-hop node's updated energy is greater than threshold value. It forwards only if it satisfies the condition or else drops the RTR packet. Figure 10 shows the TEC variation of the network with threshold value. The TEC is comparatively lesser for greater threshold values. It is because in a periodic beaconing scheme, the nodes go on forwarding the control packets regardless of their energy level. When a threshold value is set and is less, more number of forwards take place and so more

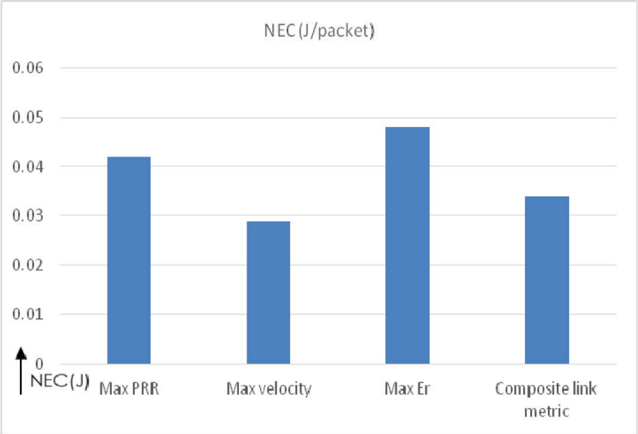


Figure 9. NEC comparison for standalone and composite metrics.

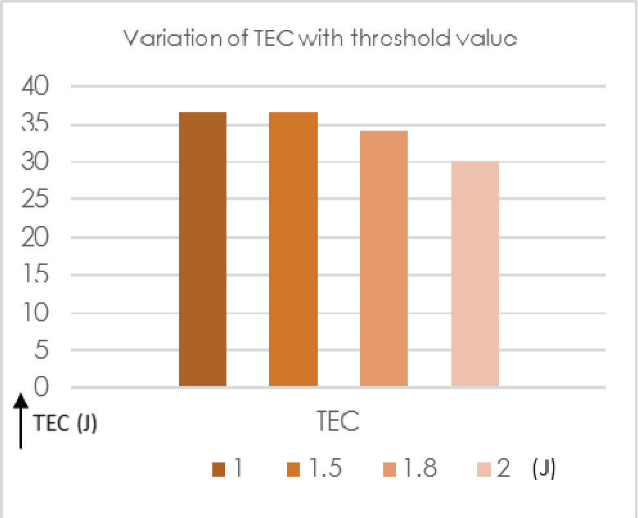


Figure 10. Variation of TEC with threshold value.

energy is expended. So in this protocol, the threshold value is set to 1.8J for optimum performance to prolong the network lifetime.

4.3 Impact of Network Diameter on Total Energy Consumption in Non-Controlled Flooding

Network diameter is the range upto which the sink floods the network. It is proportional to the number of hops taken by a packet before being dropped. The sink floods the entire network with data queries which results in faster draining of energy of the nodes, because it involves all the nodes which are not participating in data forwarding. So the network diameter is set to a lower value, so that the mobile sink floods the part of the network and collects data. This reduces the TEC of the network. Figure 11 shows the variation of TEC with network diameter. As the network diameter increases, the number of packets disseminated is more and hence the TEC increases, with increasing network size.

4.4 Performance Comparison of the Protocol with AODV, DSDV and ZRP

The routing phase of RTCD is compared to existing reactive, proactive and hybrid routing protocols AODV, DSDV and ZRP respectively and its performance is evaluated by comparing the PDR, E2E delay and NEC metrics. The zone radius of ZRP is fixed at two.

Figure 12 shows the comparison of PDR for different network sizes using log-normal shadowing model. It is observed that PDR of ZRP decreases with network size as it becomes more reactive beyond zone radius. PDR of

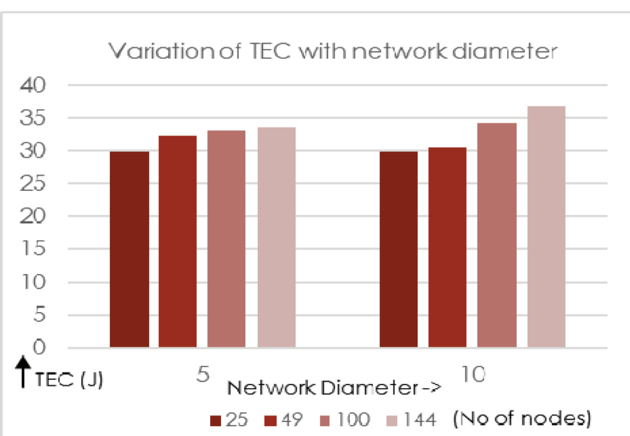


Figure 11. Variation of TEC with network diameter.

DSDV is more than that of AODV for smaller networks as it has information of all nodes in its routing table. RTCD routing has higher PDR for larger networks as it chooses the optimal node for routing.

From the Figure 13, it is evident that reactive protocol (AODV) has higher end-to-end (E2E) delay as it has to perform route discovery for routing data. E2E delay of RTCD routing is intermediate to those of other protocols. DSDV has lesser E2E delay as delay is not incurred for routing.

Figure 14 shows the NEC comparison for the protocols. It is observed that ZRP has NEC higher than AODV due to its proactive nature. The routing in RTCD has NEC intermediate of the other protocols. DSDV also has higher NEC due to periodic broadcast of control messages resulting in overhead.

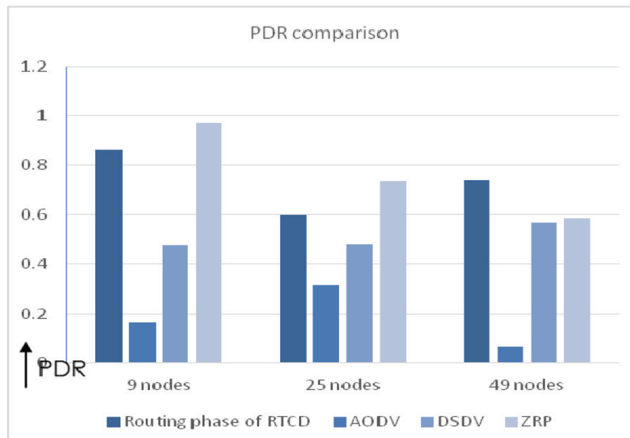


Figure 12. PDR comparison of AODV, DSDV and ZRP with RTCD routing.

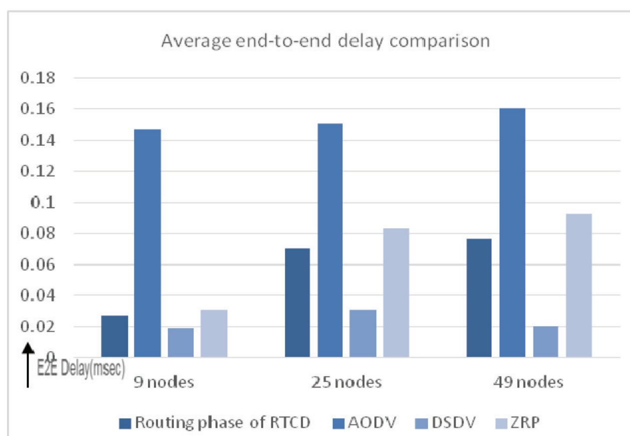


Figure 13. Average E2E delay comparison of AODV, DSDV and ZRP with RTCD routing.

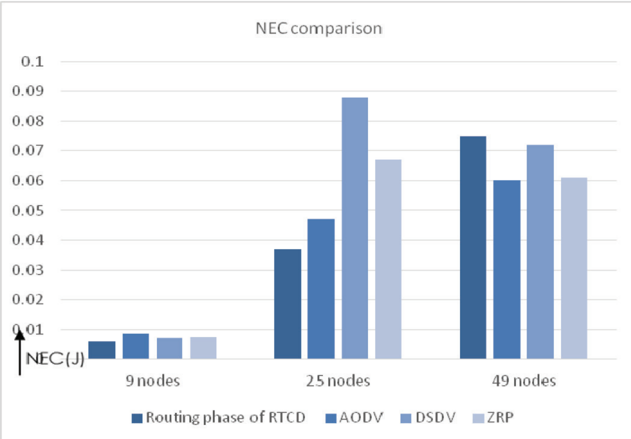


Figure 14. NEC comparison of AODV, DSDV and ZRP with RTCD routing.

5. Conclusion

In this paper, controlled dissemination of control messages by mobile sink is proposed which targets at improving network lifetime. PRR as a measure of link quality is modelled with respect to distance between the nodes, instead of location based routing which is not suitable for mobile sink environment. This is used in the composite link metric calculation for data routing. The performance of routing phase of RTCD is compared with AODV, DSDV and ZRP with respect to PDR, E2E delay and NEC. Furthermore, the effect of setting threshold value of energy and network diameter on the network is also studied. Future work may include evaluation of RTCD in real test bed network consisting of motes and also including RSSI parameter in the weighted composite link metric calculation.

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