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An Optimized QoS-based Multipath Routing Protocol for Wireless Sensor Networks

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Abstract: As the Wireless Sensor Networks (WSNs) continue to evolve, it becomes more and more significant in day today life. WSN is a promising approach, but finding optimal route discovery is more problematic due to the resource constrains of sensors and the various application requirements. The proposed Optimized Quality of Service based Multipath Routing Protocol (OQoS-MRP) for WSN is designed to find near optimal multi-hop communication path from the sink to sensors by considering various QoS metrics. The best-case multipath route selection procedure is used for transferring the data to sink. According to QoS metrics, the performance of this communication protocol is evaluated and compared with other existing protocols namely EE-LEACH and MRBCH. The simulation result shows that OQoS-MRP achieves prominent data communication while maintaining reasonable energy consumption. It also reduces the transmission delay and communication overhead on the basis of ensuring the outcome of the entire network.

Keywords: Wireless sensor networks, Quality of service, Multipath routing, OQoS-MRP.

1. Introduction

In recent years, Wireless Sensor Networks (WSNs) have become one of the developing research field, as they are envisioned to have wide applications with different phenomenon related to environmental tracking, response, security monitoring in manned or unmanned missions [1]. Recent advances in wireless technology with networking capabilities have generated a lot of interest to design routing protocols for WSNs with Quality of Service (QoS) based real-time applications [2].

A WSN is composed of huge, low power intelligent sensors with high power sink and are responsible for establishing paths among themselves with certain transmission regulations [3, 4]. Wireless sensors are more advantageous due to their simple installation, self-identification, self-diagnosis and time awareness for coordination with other sensors to form dynamic self-organized networks. But, it is tightly constrained with limited energy, memory, analytical and computational ability and low data rate as well as short range for wireless radio transmission [5, 6]. In WSN, the routing protocol ensures that the data reaches the sink possibly across multi-hops. The best routing protocol should have the following characteristics namely routing without loops, minimal routing overheads, automatic load balancing, recovery from link failures, congestion avoidance mechanism, energy efficiency as well as QoS. But, the design of routing protocol for WSNs is influenced by many challenging factors like dynamicity, heterogeneity, resource scarcity and so on. These factors must be overcome before efficient communication can be achieved in WSNs. One of the primary challenges faced by WSNs is energy constrained. In many applications, sensors are equipped with the battery and functions without maintenance and recharge. Hence, it is essential to plan for the energy efficiency of the sensors so that the overall lifetime of the network can be enhanced. This characteristic motivates to design an energy efficient routing protocol which can achieve the goal of minimum energy consumption in WSN [7].

Furthermore, the QoS is highly needed in case of reliable and delay sensitive applications. Therefore, enabling such applications in WSN requires QoS awareness which is to be considered at all layers of the protocol stack especially at the network layer in order to guarantee reliable packet delivery and end-to-end delay [8]. The design of routing protocol is resilient to frequent path disruptions caused by node or link failure and collision. Some of the routing protocols find routing path but often fails during data transmission, which decreases the reliability. The solution to this problem is designing an enhanced multipath routing protocol. Multipath routing protocol allows numerous paths between the source and the sink. So if one of the paths fails, data can be sent through an alternative path. This process enhances the reliability with minimum latency of the network. This motivated us to employ the concept of multipath routing for reliable transmission, which reduces the control overhead for route discovery and increases the throughput of the system [9].

Therefore, this paper is designed to propose an Optimized QoS based Multipath Routing Protocol (OQoS-MRP) for WSN to establish multipath routing by considering the multi-constrained QoS metrics namely reliability, energy consumption and delay. In OQoS-MRP, the process of selecting the routing path is assigned to the sink because of the unlimited resources at the sink. Therefore, the sink initiated the route discovery process which is required for selecting the next hop node in the network based on topological structure and QoS metric values of the neighbor nodes. If an event occurs, the data transfers to the sink across best-case multipath, which distributes the traffic load. Thus, the proposed routing protocol may provide better data throughput while minimizing packet loss with minimum delay and enhance the lifetime of the network.

2. Literature review

The routing for WSNs is tough problem due to the inherent characteristics that distinguish from other wireless networks. Routing protocols designed for WSNs which differ from different perception depending on their application, architecture and goal.

Ganesan et al., [10] have presented a disjoint multipath routing, which is a distributed algorithm based on local information and achieve load balancing. This algorithm uses a primary path to transfer data. An alternative path can be used when the primary path fails. However, this algorithm is not suitable for extending lifespan of the network. De S. et al., [11] have proposed a meshed multipath routing with an efficient strategy. This algorithm achieved a better throughput than the traditional multipath algorithms. However, this approach needs nodes to be equipped with Global Positioning System (GPS), which maximizes the cost of the node.

Younis et al., [12] have presented a clustering protocol named as Hybrid, Energy-Efficient Distributed (HEED), which prolonged the lifespan of the sensor network. This protocol has formed the clustering and cluster head selection based on the node degree, communication cost and residual energy of sensors. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. However, the cluster selection deals with only a subset of parameters, which can possibly impose constraints on the system. Y. Yang et al., [13] have proposed a Multipath Routing protocol Based on the credible Cluster Heads (MRBCH) that taken into consideration for both energy efficiency and security. This protocol selects the high energy node as cluster head and then authenticates it by the neighbor cluster heads. Using trust mechanisms, the credit value is generated and exchanged among the cluster heads exclusively. By using multipath cluster head routing based on the credit value ensures a high quality route and prolong the lifespan. Arumugam et al., [14] have introduced an Energy-Efficient Low Energy Adaptive Clustering Hierarchy (EE-LEACH) protocol, which improved the lifespan and data ensemble of the network. The coverage probability is derived with respect to the Gaussian distribution. In this system, a cluster head is elected for each cluster, which has the maximum residual energy. Also, conditional probability theorem is used for node aggregation. It provide better packet delivery ratio with lesser energy utilization. But it lacks to provide the confidentiality and integrity of data.

In QoS based routing protocols, the sensor network has to balance between energy consumption and data quality. Sohrabi et al., [15] have presented a Sequential Assignment Routing (SAR), which uses tree architecture to route data packets in multiple paths. This algorithm takes routing decision based on the QoS metrics on each path, the priority level of each packet and energy resource. To transmit data to sink, SAR computes a weighted QoS metric, which is the product of the additive QoS metric and a weight coefficient associated with the priority level of that packet. Although, SAR ensures energy efficient, fault-tolerance and easy recovery but suffer from large scalability of sensors.

The protocol must periodically recalculate the routes to be prepared in case of topology changes due to node failure. T. He et al., [16] have proposed a stateless real-time communication protocol SPEED. This is another location based QoS routing protocol, which provides soft real-time end-to-end guarantee with a desired delivery speed across sensor networks. Felemban et al., [17] have presented a Multipath and Multi-speed routing protocol (MMSPEED), which maintenances various speed services and probabilistic QoS guarantee in order to avoid congestion and decrease the packet loss rate. This protocol is scalable for large networks, but the energy metric is not taken into consideration. X. Huang et al., [18] have proposed a Multi-Constrained QoS Multipath routing Protocol (MCMP), which improves the network performance with reasonable energy consumption. This protocol has used braided multipath to send data packets according to QoS metrics namely reliability and delay. The problem of end-to-end delay is solved by using linear integer programming. However, this protocol routes the data over the minimum hop count path to satisfy the required QoS, which leads in some cases to consume more energy. Hind Alwan et al., [19] have presented a Multi-objective QoS Routing (MQoSR) protocol. In MQoSR, the requirements of an application are modeled as multiple QoS classes in terms of reliability, delay and energy. In particular, the problem of providing QoS routing is formulated by using a heuristic neighbor selection mechanism that uses the geographic routing mechanism combined with the QoS requirements to provide MQoSR for different application requirements.

3. Proposed routing protocol for WSN

3.1 Network environment and assumptions

A WSN is modeled as an undirected weighted graph $\mathrm{G}(\mathrm{V}, \mathrm{E}, \mathrm{W})$, where $\mathrm{V} = \{v_1, v_2, \dots v_n\}$, denotes the finite set of vertices that represent the sensors, $E = \{(v_1,\ v_2), \dots\ (v_{n-1},\ v_n)\}$, indicates the finite set of edges that represent the bidirectional wireless links and W is the weight set of all links. In this paper, we assume that the sensors are heterogeneous, dynamicity and have unique ID. Each sensor has uniform transmission radius r and its neighbor nodes are randomly distributed within the area of πr^2. Each sensor computes its residual energy level as well as energy depletion which vary depending on the location of a sensor to transfer a bit of data [20].

3.2 Optimized QoS-based multipath routing protocol (OQoS-MRP) for WSNs

The proposed OQoS-MRP for WSN is formulated as link-based and path-based metrics. Each sensor is able to record the link performance between itself and its neighbor in terms of reliability (R_{link}), energy (E_{link}), delay (D_{link}), distance to sink and hop count. The path-based metrics are represented as (R_{path}), (E_{path}) and (D_{path}). In multipath routing, to find the total end-to-end guarantee on all the used paths is divided into end-to-end reliability (R_{e2e}), end-to-end energy consumption (E_{e2e}) and end-to-end delay (D_{e2e}). The proposed protocol is divided into three phases. The first phase establishes neighbor discovery and topology construction, the second phase finds the shortest optimal path using SingleSink-AllDestination algorithm and the last phase provides the procedure for actual data routing.

3.2.1. Neighbor discovery and topology construction

After the deployment of sensors, the sink initializes neighbor discovery phase. In this phase, each sensor broadcasts an initial *hello message* to all neighbors in the communication area and then updates the local status of its active neighbors periodically.

Topology construction phase starts, after neighbor discovery phase. Instead of flooding, each sensor uses multicasting technique to transmit their neighbor information to sink through relay nodes as shown in Fig. 1. The sensor (v) selects the relay node from $Nbr(v)$, which is a set of neighbor node of v and send Nbr-Info packet only once, which avoid looping in the network. This process reduces the traffic in the network and saves the energy. Each sensor keeps a received neighbor information list. The sink creates the neighbor adjacency matrix when it receives the Nbr-Info from the sensors is shown in Table 1.

This matrix is a $(n+1) \times (n+1)$, where n is the number of sensors in the network and a sink. The adjacency matrix shows the network topology and connectivity among these nodes. Based on adjacency matrix, the sink chooses the routing paths from source to the sink.

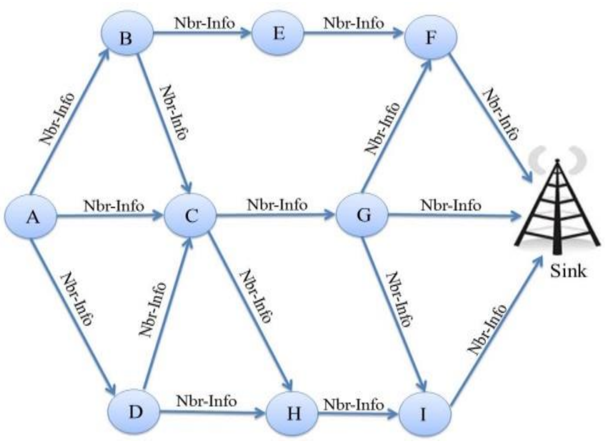

Figure.1 Sensors send the Nbr-Info packet to the sink

Table 1. Neighbor adjacency matrix

	A	B	C	D	E	F	G	H	I	Sink
A	0	1	1	1	0	0	0	0	0	0
B	1	0	1	0	1	0	0	0	0	0
C	0	0	0	0	0	0	1	1	0	0
D	0	0	1	0	0	0	0	1	0	0
E	0	0	0	0	0	1	0	0	0	0
F	0	0	0	0	0	0	0	0	0	1
G	0	0	0	0	0	1	0	0	1	1
H	0	0	1	1	0	0	0	0	1	0
I	0	0	0	0	0	0	0	0	0	1
Sink	0	0	0	0	0	1	1	0	1	0

3.2.2. Route discovery phase

In this phase, each sensor broadcasts an application-specific threshold values $\{R_{req}, E_{min}, D_{req}\}$ to all its active neighbor sensors through *route-request message*. The neighbor sensors check whether it satisfies the application-specific threshold values and then it sends *route-reply message*. The format of route-request and route-reply message is shown in Fig. 2 and Fig. 3 respectively. The route-reply message is unicast whereas the route-request message is broadcast.

Figure.2 Format of route-request message

Figure.3 Format of route-reply message

Each sensor stores QoS constrains satisfied neighbor table (Table 2) for link values associated with each neighbor and updated in order to select the next node with minimum cost.

Table 2. QoS constrains satisfied neighbor table

Neighbor ID	1	2	..	n
$\boldsymbol{R_{link}}$	R_{v1}	R_{v2}	..	R_{vn}
$\boldsymbol{E_{link}}$	E_{v1}	E_{v2}	..	E_{vn}
$\boldsymbol{D_{link}}$	D_{v1}	D_{v2}	..	D_{vn}
Hop count	$hop_{1,sink}$	$hop_{2,sink}$	..	$hop_{n,sink}$
Distance to Sink	$d_{1,sink}$	$d_{2,sink}$	..	$d_{n,sink}$
Cost	$cost_{v1}$	$cost_{v2}$	.	$cost_{vn}$

Thus, the OQoS-MRP finds a set of available paths, $P = \{path_1,\ path_2,\ ..path_{np}\}$ from the sink to all sensors by satisfying the following objective function

$$f : \max(f_R), \min(f_E), \min(f_D) \quad (1)$$

which can be written as

$$\mathbb{Z} \sum_{p=1}^{np} f_p \ x \, W \quad (2)$$

where W is the weight set of non-negative QoS threshold values required by an application. In Eq. (1), the first term specifies the maximum data transmission reliability, the second term denotes the minimum energy consumption and the last term specifies the minimum amount of delay in data transmission. Hence, the objective function is to minimize the data transmission delay while maximizing the data transmission reliability. And also it minimizes data transmission power in order to extend the network lifespan. These QoS constrains are subject to

$$f_R \geq R_{req} \quad (3)$$

$$min \sum f_E \quad (4)$$

$$f_D \leq D_{req} \quad (5)$$

Then, by using these constrains, the cost of link (cost_{vw}) is calculated by

$$cost_{vw} = \frac{R_{req}}{R_{vw}} + \frac{E_{vw}}{E_{min}} + \frac{D_{vw}}{D_{req}} \quad (6)$$

The sink is responsible for establishing a communication path to all sensors by executing greedy algorithm SingleSink-AllDestination( ) to find optimal solution from the set of feasible solutions. First, the sink starts to select next hop best neighbor node with minimum cost by comparing half of adjacent neighbors in the coverage area near by the sink. The best neighbor node is added to the shortest path list. Again, this neighbor node forwards same route-request message to its active neighbors. This local search procedure is used to refine the optimal solution in the end of each iteration. This process is repeated until the shortest path to all active nodes in the sensor network has been found.

```
        Algorithm 1. SingleSinkAllDestination( )
Procedure SingleSinkAllDestination( )
Begin
   Initially all vertices visited array is set to 0
   i = 0;
   while (i <= n)
      if (visited[i] = 0) then
           path_cost = hop_count = 0;
           R_path[i] = E_path[i] = D_path[i] = 0;
           call OptimalRouteDiscovery(i);
      i = i + 1;
    end while
End SingleSinkAllDestination

Procedure OptimalRouteDiscovery (v)
Begin
   min_cost = -1;
   vistited[v] = 1;
   for each vertex w adjacent from v do until to
cover half of the vertices in the coverage area
near by the sink
        if (visited[w] = 0) then
/*Choose the best node among their neighbor
nodes by calculating cost of link performance
based on QoS metric {R_link, E_link, D_link}, the distance
from sink and number of hop counts */
           cost_vw = R_req /R_vw+E_vw/E_min+ D_vw/ D_req;
/* Compare it with all adjacent nodes in the half
of coverage area, then choose the best node*/
     if (cost_vw<min_cost) then
           best_node = w;
           min_cost = cost_vw
  end for
/*Select best_node among their neighbor nodes*/
  optimal_path= union {optimal_path, best_node};
  path_cost = path_cost + min_cost;
  path_count = path_count + 1;
  R_path[i] = R_path[i] X R_vw;
  E_path[i] = E_path[i] + E_vw;
  D_path[i] = D_path[i] + D_vw;
  call OptimalRouteDiscovery (best_node)
End OptimalRouteDiscovery
```

3.3.3. Data transmission phase

A sensor can play the role of a source or a forwarding sensor. A sensor senses the occurrence of an event (source) or a data packet arrives to it (forwarding sensor). If the sink and the source or the forwarding sensors are in the same coverage area then the packets can be sent directly to the sink in a single-hop communication. Otherwise sensor forwards the packet to the sink through multi-hop communications. The proposed algorithm uses both single path and multipath routing in order to select the near optimal route with minimum cost. When an event occurs, source sensor sends data towards one of the neighbor sensor as the next hop in its coverage area by looking up its routing table which fulfills the following criteria

- The neighbor node is the most nearest neighbor to the sink with minimum hop count with respect to other neighboring nodes.
- Residual energy of the neighbor node is greater than or equal to threshold value.
- To select minimum cost path under the transmission strategy.

The next data packet will also be sent to an alternative neighbor, which is the best-case multipath routes to reach the sink and fulfills QoS constrains. The number of paths used to route data can be defined as the transmission strategy (TS) and is given by

$$TS = \begin{cases} i & if\ T \geq i \geq 2, multipath\ routing \\ 1 & single\ path\ routing \end{cases} \quad (7)$$

where T is application-specific threshold value and dynamic selection of $path_i$, iϵnp.

```
              Algorithm 2. BestPathSelection()
Procedure BestPathSelection()
Begin
   Initialize the parameters
   sort Ascending order by path_cost;
   /* when an event occurred*/
   while (!end of event)
        if (path_count = 1)
            Single path routing;
        else
            Select any one of the path from 1 to T and
            then route data to sink;
            R_e2e = 1-(R_e2e X (1-R_path[i]));
            E_e2e = E_e2e + E_path[i];
            D_e2e = D_e2e + D_path[i];
  end while
End BestPathSelection
```

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In the data transmission algorithm, the selection of next path is limited to a subset of the set of best-case paths based on the T value. The probability selection of a neighbor to be chosen as the next hop by a sensor has a direct relationship with the cost of link value associate to this neighbor. The BestPathSelection procedure is towards distributing the traffic load among two or more paths. This way, the approach not only uses building excessive subsets but also improve the performance of WSN. The packet relay responsibility must be shared among sensors in order to avoid routing bottlenecks and sensors early death. Load distribution is to avoid the congestion problems in the sensor network and to increase data delivery ratio.

4. Results and discussion

4.1 Simulation results

Initially, some application-specific QoS threshold metric values are declared and established for a system model. In this section, the simulation results are presented using Network Simulator tool, version 2.35. The parameters and their values chosen are shown in Table 3.

4.2 Performance analysis

The proposed algorithm OQoS-MRP for WSN is compared with the existing routing protocols namely EE-LEACH and MRBCH using the same initial values and the same scenario with different parameters.

Table 3. NS2 simulation configuration parameters

Parameters	Values
Radio Propagation Model	Two-ray ground reflection model
MAC Type	IEEE 802.15.4
Antenna Type	Omnidirectional
Simulation area	300X200m
Link bandwidth / Data rate	250kbps
Radio Frequency	2.4GHz
Number of nodes	50, 100, 150, 200, 250
Simulation time	300s
Channel Type	channel/wireless
Queue Type	Priority Queue
Initial energy	3J
Transmission power consumption	0.002*dist J
Reception power consumption	0.02 J
Routing Protocol	OQoS-MRP
Traffic source	CBR
Packet Size	32 bytes

The performances of various QoS metric used in the simulation are discussed below.

Network lifetime: Sensor network lifetime depends on the number of active sensors and connectivity among them in the network, so energy must be used efficiently in order to maximize the network lifetime. Fig. 4 clearly shows the network lifetime comparison between the proposed OQoS-MRP and existing EE-LEACH, MRBCH routing protocols. It is found that the proposed method enhance the lifetime of the network because it uses limited control packets and balances the load among the sensors.

Total energy consumption: The total energy consumption is the sum of energy or power consumed by all sensors in the network to transmission and reception of control and data packets over the simulation time. . This parameter is vital as it determines the overall lifetime of the network. Fig. 5 shows that the proposed method effectively consumed minimum amount of energy when compared with the existing protocols. That is OQoS-MRP consumes 2.22% and 5.59% less energy than EE-LEACH and MRBCH routing protocols respectively.

Throughput: It is defined as the number of packets received at a particular point of time. Fig. 6 shows the results of the proposed OQoS-MRP method which has high throughput because of multipath routing. The proposed method achieves throughput value of 51.696 Kbps which is 5.102 Kbps and 7.673 Kbps higher than EE-LEACH and MRBCH respectively.

Packet delivery ratio (PDR): PDR is the ratio of number of actual data packets successfully received by the sink to the total number of data packets sent by the source in the network. This metric indicates the reliability of the routing protocol. Fig. 7 clearly shows that the PDR of the proposed method is 89.40% which is 8.97% and 17.31% higher than EE-LEACH and MRBCH methods respectively.

End-to-end delay: The end-to-end delay is measured as the total latency experienced by a packet routed from a source to the sink inside the network. It considers all types of delay such as transmission delay, queuing delay, processing delay and so on. This metric signifies the robustness and determines the speed of node in the network. The impact of proposed OQoS-MRP method on end-to-end delay shown in Fig. 8 is minimum when compared with the existing competitive protocols.

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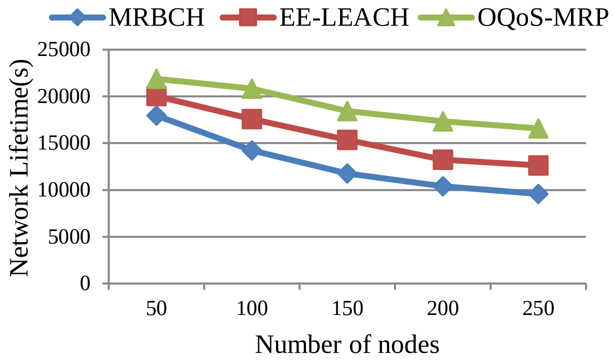

Figure.4 Network lifetime

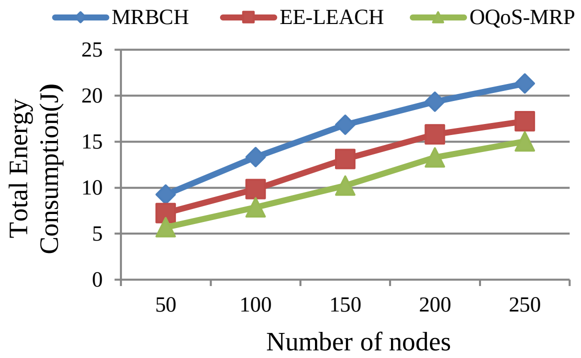

Figure.5 Total energy consumption

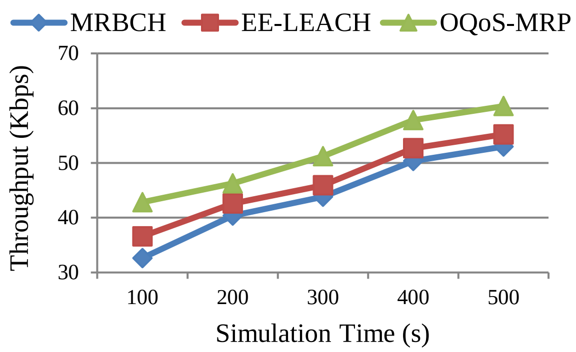

Figure.6 Throughput

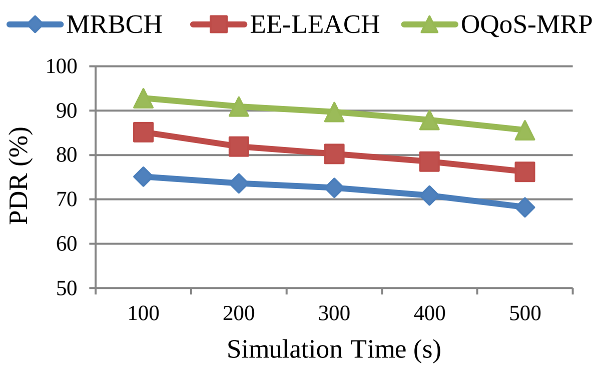

Figure.7 Packet delivery ratio (PDR)

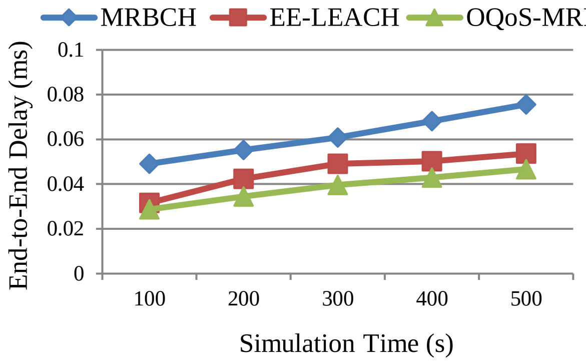

Figure.8 End-to-end delay

5. Conclusion

An Optimized QoS based Multipath Routing Protocol (OQoS-MRP) for WSNs is proposed to establish near optimal routes for data transmission under the multi-constrained QoS. The SingleSink-AllDestination algorithm is used to find the next hop neighbor. The simulation results are evaluated and compared with the existing protocols EE-LEACH and MRBCH. The performances of these protocols are evaluated with respect to the QoS. The simulation results showed that the proposed protocol achieves better communication reliability with minimum delay while maintaining reasonable energy consumption and enhance lifetime of network. Furthermore, OQoS-MRP achieves better load balancing by dynamically choosing alternate path from subset of best-case paths to transmit data. Hence, the principle of optimality holds.

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