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Energy efficient and QoS aware routing protocol for Clustered Wireless Sensor Network ☆

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ABSTRACT

In this paper, a protocol called Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed. To ensure QoS for different traffic types, prioritization of data is done based on message type and content. To address energy efficiency (hotspot problem) and high end-to-end delay problem, a combination of mobile and static sink is used for data gathering. Delay sensitive message are sent through the static sink and delay tolerant message are send through the mobile sink. Consequently, EEQR incurs less end-to-end delay, is energy efficient as well as able to ensure QoS. To evaluate the performance of the proposed strategy, intensive simulations are carried out. Performance of the proposed strategy is compared with the static sink and mobile sinks strategies. The results demonstrated that EEQR has prolonged the network and coverage lifetime, as well as has improved the other QoS routing parameters, such as delay, packet loss ratio, and throughput.

1. Introduction

The collection of large number of sensor nodes densely deployed in an area to detect some physical phenomenon is termed as Wireless Sensor Network (WSN) [1,2]. A classic architecture of WSN includes randomly deployed sensor nodes near to which Base Station (BS)/sink is placed. Sink is connected to internet through any other wired or wireless network. Sink gives instructions to sensor nodes and gathers sensed data from them. As per the application requirement, sensor nodes, sense the desirable physical phenomenon and locally do the data aggregation to avoid communication of redundant data. It sends the sensed aggregated data to sink using hop-by-hop communication. Once a sink receives sensed data, it processes and forwards it, which is easily accessible to the user through internet.

Collecting data from source sensor nodes to sink is a common and challenging task in many WSN applications. Generally, sensor node does not have power and communication range to directly forward the sensed data to the BS. Hence, a sensor node would not only sense and send its own data but also act as router and propagate the data of its neighbors. In a typical WSN architecture, the sink is static [3] and using multi-hop communication all the nodes in the network forward their data to the sink. Consequently, nodes near to the sink deplete their battery power; problem is termed as hot spot problem. As a result, though the nodes farther from the sink has significant energy left but their energy cannot be utilized as the nodes near to the sink have depleted their energy. Hence, sensed data cannot be sent to the sink across hot spot or energy hole near the sink. It can significantly minimize network lifetime. Static nature of the sink is the main reason behind the hot spot problem, as all the time same nodes near the sink has to forward the data. Main advantage of the static sink approach is that it involves less end-to-end delay.

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In recent years, contrary to static sink, mobile sink approach [4] has attracted much research interest because of increase in its potential WSN applications. It has potential to improve network performance such as energy efficiency and throughput. But main disadvantage of mobile sink approach is that it encounters long end-to-end delay.

In routing, most of the protocols found in literature [5], considered energy awareness as key design issue to maximize the network. Factors like throughput, latency and delay are not issues of primary concern in these protocols and approach is acceptable, since mostly they are dealing with small amount of data flowing in low rates. However, with the emergence of new WSN application that involves multimedia and imagining sensors, routing in WSN has faced new challenges. Reporting of data in these multimedia and imaging WSN application, requires minimum end-to-end delay within acceptable limit. In such application, in addition to energy efficiency; latency, throughput and delay also becomes issues of primary concern. Such performance metrics are usually referred as quality of service (QoS) of the communication network.

To have efficient use of sensor node energy and ability to report the imaging and multimedia data in timely manner within acceptable range, requires both energy and QoS aware routing protocol. Thus, there is need of paradigm shift from conventional energy efficient protocols to the recent QoS aware energy efficient protocols. WSN application which benefits from QoS aware protocols includes military surveillance, real time target tracking in battle environments, tsunami alarm, smart hospitals, seismic detection, biomedical health monitoring, hazardous environment sensing, fire detection, intrusion detection, disaster monitoring, and real-time control. Generally, these applications deal with real time data and need certain bandwidth with minimum possible delay. In such scenarios, to guarantee the reliable delivery of the real-time data [6], service differentiation mechanism is needed. QoS aware energy efficient routing in WSN will provide the energy efficient path as well as guarantee certain bandwidth with minimum possible delay. The need of QoS aware energy efficient schemes that can prolong the network lifetime as well as guarantee QoS motivated us to do this. Main Motivation behind this work is to study various issues and strategies of QoS aware energy efficient data gathering, and propose QoS aware energy efficient routing protocol for wireless sensor networks. Proposed protocol considered energy efficiency as well as QoS as primary design objective and can be applied to emerging delay constrained WSN application. As underlying data gathering architecture, among the existing protocols, the cluster-based structure has been widely pursued by the research community as an effective architecture for data-gathering in WSN. This paper also uses clustering as underlying architecture [7,8].

In this paper, the two approaches of the static and mobile sink are combined. It gives advantage of low end-to-end delay of static approach and energy efficiency of mobile sink approach which minimize the hotspot problem. Furthermore to provide QoS, prioritization of traffic is done based on the delay and bandwidth requirement of each class of application. To achieve QoS and energy efficiency in this paper, Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed.

These measures ensure balanced use of energy among the nodes and improve the QoS parameters like delay, packet loss. Main contributions of this paper are as under:

- First, effectiveness of using combination of static and mobile sink, and differentiated forwarding scheme for different types of traffic (based on their bandwidth and delay requirement) is discussed. Use of categorizing in coming traffic into different classes and prioritizing them based on the variable delay and bandwidth requirements is advocated, in contrast to generic data forwarding approach.
- Second, Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed to address delay minimization and lifetime maximization problem. Following are two main contribution of the proposed protocol:
  – To reduce delay, EEQR identifies different traffic types having different bandwidth and delay requirements at two levels: (a) Nodes traffic is divided into different traffic types, as each type of traffic has got different delay and bandwidth requirements. Traffic classes are prioritized differently to fulfill fair QoS for each class of traffic. (b) Nodes traffic is prioritized based on the packet content type. As WSN has limited resource thus sensor node should forward only the important data. (c) To complement reduction in delay the movement of mobile sink is associated with the how much priority message is accumulated at each point.
  – To increase the network life time and minimize delay, combination of mobile and static sink is used. (a) Static sink generally face the hotspot problem by the excessive forwarding of the packets at the nodes near to the BS. To reduce this only higher priority packets are forwarded to the static sink and other low priority packets are being sent by the mobile sink. (b) Mobile sink generally face the problem of long delay as all the nodes have to wait for the mobile sink to come in the vicinity of the data forwarding nodes. To address this problem, concept of prioritization of traffic is use and movement of mobile is associated with traffic priority.
- Third, extensive simulations are carried out to evaluate the performance of the proposed protocol, by comparing its performance with static sink and mobile sink approaches. The results demonstrated that EEQR has successfully minimized the end-to-end delay, as well as has improved the other QoS routing parameters like average energy per packet, packet loss ratio, and throughput.

The remainder of the paper is organized as follows. In Section 2, a related work is discussed. In Section 3, Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor is proposed and explained. Simulation results are presented in Section 4. Section 5 concludes the paper with conclusions.

2. Related work

Data gathering in WSN is usually performed by sensor nodes relaying data towards a static control centre using multi hop communication. In static sink, data is delivered to the BS, using multi-hop communication involving many sensor nodes on the way to BS. It results in early depletion of energy of some nodes, thus forming energy hole. Since, sensors near the sink have to participate in relaying data on behalf of other sensors. Thus will drain their energy very quickly, resulting in network partitioning and limitation of the network lifetime.

In WSN, recently a novel approach of using mobile sink in WSN is catching momentum. Approach involves movement of sink inside the network area to collect the data and minimize cost. Approach getting popularity by emergence of its important application (mostly associated with pervasive sensing and ubiquitous computing). Factors contributing to use of mobile sink is motivated by the imminent growth in increasing number of event-based user-centric network applications like ambient intelligence applications, remote monitoring, smart buildings/rooms, rescue missions, intrusion detection and other pervasive computing applications. Sink mobility has shown potential to improve network performance such as energy efficiency and throughput. A number of approaches exploiting sink mobility have been proposed in recent years [9,10]. These approaches can be divided into two categories: proactive approach and reactive approach. In proactive approach sensor node readings are pushed to storage nodes from where they were collected by mobile sink. Whereas, in reactive approaches, reading from the sensor nodes were pulled by the roaming mobile sink when it moves in the network.

The following is an explanation of some important research efforts which use mobile sink.

In [11], mobility of sinks for increasing the lifetime of low powered WSN is considered. Linear programming formulation is done for both determining the movement of the sink and the sojourn time at different points in the network. Model differs from the previous solutions because it directly aims at maximizing network lifetime instead of reducing total energy consumption during data communication, which is what was done in previous solutions.

In [12], Data Stashing is proposed, where packets are accumulated to a single forwarding node as well as to its neighbor nodes. To forward data, neighbor nodes will wait until they are in the vicinity of the sink node. It increased packet delivery ratio and decreased latency, but, requires more energy and storage.

In [13], it is advocated that, for large networks using a single mobile element may not be sufficient, and would require multiple sinks. Consequently, multiple controlled mobile elements are used for data collection. Furthermore, load balancing algorithms is proposed which runs periodically and do the load distribution among multiple mobile elements. It tend to balance the number of sensor nodes each mobile element services.

In [14], an autonomous moving strategy for the mobile sinks in data-gathering applications is proposed. The data gathering period was divided into three phases: moving the sink, collecting data, and notifying sensors of the sink's positions. Additionally, to balance energy consumption among sensor nodes and prolong network lifetime, an autonomous moving strategy for the mobile sink is proposed. Mobile sink moves towards the nodes with high residual energy, thus enforcing data forwarding be done by high energy node near the sink. During movement, sink avoid passing by the nodes with low energy.

In [15], a comprehensive survey of the protocols is given which uses nodes mobility to extend the network lifetime. It gives overviews and comparisons of protocols by dividing them into three groups namely: mechanisms using mobile sinks, mechanisms using mobile sensors redeployment, and mechanisms using mobile relays. Protocols using mobile sinks, achieves balance in energy consumption in the whole network by using shorter multi-hop data delivery paths. Energy balancing is supplemented by time to time change in the set of sensors located near a sink by regular sink movement. Protocols using mobile sensors do relocation after initial deployment, to balance energy consumption and to improve network lifetime. Protocols using mobile relays, avoid long distance communication by using mobile nodes as relay node. These mobile nodes are responsible of carrying data to the sink. Furthermore, these mobile nodes also do the job of co-locating static sensors.

In [16], the time (stay value) how long mobile sink stay at a particular position is calculated by metrics like average residual energy and the number of neighbors. Mobile sink will move to the new location with the highest stay-value. The scheme can achieve balance energy consumption and avoid nodes near to the sink to drain their energy quickly.

In [17], the problem of traffic management in the WSN with a mobile sink is addressed. Effect of sink mobility on traffic load in WSN is explained. To effectively adapt to sink relocations, an adaptive routing with load estimation techniques are proposed. Approach considers network load as well as path quality variations to facilitate sink relocation. Furthermore, paper proposes two algorithms to do optimization through joint congestion and reliability aware relocation.

In [18], a distributed algorithm for a single mobile sink sensor network is proposed. Algorithm is based on the standard sub gradient method and minimum cost flow ε-relaxation algorithm. Objective is to achieve the maximum lifetime of a sensor network.

In [19], a collection of mobility patterns and data collection strategies are presented for different applications. Experimental comparison demonstrates that for applications where time efficiency is not critical, sink can move in the whole network area. It is suitable for application which needs to save energy and can tolerate delays. For applications where energy efficiency is not critical and sink mobility is limited. The best approach is to follow a fixed trajectory with multi-hop data propagation, as it offers much less delay.

In [20], three new protocols for data gathering in WSN with mobile sink were proposed. It investigated the impact of having many mobile sinks and using combination of static and mobile sinks. Furthermore, distributed protocol is proposed which improves performance by equally spreading the sinks in the network. In these protocols, randomization is used and protocol works using local information.

In [10], architecture of wireless sensor networks with mobile sinks (MSSNs) is developed. MSSN achieves energy efficiency by converting multi-hop communication into single hop transmission. Furthermore, a transmission-scheduling algorithm (TSA-MSSN) is proposed. It manages the balance between successful information retrieval and the minimization of the energy-consumption.

In [21], multiple mobile BS are used to provide data delivery and protocol referred as Two-Tier Data Dissemination (TTDD) is proposed. Here, sensor nodes are static with location awareness and sinks are mobile. To forward data to the mobile sinks, each data source builds a grid structure in proactive manner. On event occurrence, each sensor node builds grid structure, where, data source is chosen as start crossing point. It forwards the data announcement message to its four crossing points adjacent to it. At the end of this process, the grid structure is acquired, using which BS floods the query to the nearest dissemination point.

In [22], the problem of load balanced data collection in wireless sensor networks is investigated. Existing multi-hop routing protocols are used for improvement in network lifetime by using the base station mobility. Analytical model showed that, increase in network life time could be achieved by arbitrary mobility trajectory of the base station.

Through the extensive literature review, it is concluded that a number of papers could be focusing independently either on energy efficiency or QoS in WSN. But to the best of our no work consider QoS aware energy efficient data gathering in hybrid (static, mobile sink) based clustered wireless sensor network to maximize energy efficiency and minimize end-to-end delay using QoS based prioritization approach.

In this paper, energy-efficient data gathering in WSN is considered. For this reason, Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed. The main objective of EEQR is to provide QoS aware energy efficient data gathering by using combination of static and mobile sink with prioritization of data based on QoS requirement (bandwidth, delay).

3. The proposed protocol

3.1. Problem description

In the proposed protocol following three problems are addressed:

Firstly, in a typical WSN architecture, the sink is static and sensor nodes use multi-hop communication to forward their data to the sink. Hot-spot problem is an inherent phenomenon in WSN with static sink and can significantly decrease the lifetime of the overall network. Static nature of the sink is the main reason behind the hot spot problem, as all the time same nodes near the sink has to forward the data. With this drawback static sink approach comes with obvious advantage that it involves minimum end-to-end delay, as the nodes can send at anytime using multi-hop communication. With mobile sink approach, data forwarding to the mobile sink is performed by moving the mobile sink across the whole WSN, by which nodes sends data to mobile sink when it comes in its vicinity, either directly or using multi-hop communication. Mobile sink approach although by virtue of sink mobility gives considerable energy saving but potential disadvantage of this technique is that as sensor node have to wait for the mobile sink to come into its vicinity to do the communication, it result in increasing end-to-end delay. This increase in end-to-end delay is not acceptable for delay sensitive application. With the drawback of increased end-to-end delay, mobile sink approach comes with obvious advantage that it minimizes the hotspot problem and considerably improves the energy efficiency.

To address energy efficiency (hotspot problem) in static sink approach and high end-to-end delay in mobile sink approach, in proposed protocol a combination of mobile and static sink is used for data gathering. Delay sensitive message are sent through the static sink and delay tolerant messages are send through the mobile sink when it comes in the vicinity of the nodes. Furthermore, to minimize delay in mobile sink data gathering, movement of the mobile sink is associated with the node's priority messages. In this way, proposed protocol incur less end-to-end delay by virtue of static sink and has got energy efficient data gathering by virtue of mobile sink.

Secondly, with increase in multimedia WSN application, recently, QoS in data gathering is emerged as critical issue. Sensor node generate different type of traffic which has got its own delay and bandwidth requirements. It needs some packet prioritization mechanism to ensure those messages are fairly treated as per their distinct QoS requirement. But generally in packet forwarding protocols all the packet have got same level of priority. It results in forwarding the potentially low priority message type which can tolerate delay and make real time traffic to wait (which cannot tolerate delay). It is only because the low priority message generated earlier by the sensor node. To address this problem incoming traffic is divided into different types, based on the different delay and bandwidth requirements of traffic class. The distinct classes are given different priorities where the real time traffic has highest priority and best effort text data has lowest priority. Decision of packet forwarding is based on the priorities assigned to the packets. To be fair with all types of traffic the priorities of all the packets increase with increase in their queue wait just to make sure that low priority packets may not have to suffer indefinite delay.

Thirdly, different messages generated by a sensor node have got different level of importance. Sending all message generated by the sensor node all the way to the sink, involves usage of scarce energy resource of sensor node. This approach exhaust the energy resource of the WSN, in propagating unimportant message, while other more important message wait for their turn to be forwarded. It is only because the low priority message (unimportant routine message) generated earlier by the sensor node. To address this problem incoming traffic is prioritized into different types of message based on the importance of packet content. It results in giving priority to the high priority important packet in forwarding the data, in comparison to the less important/routine packets. Hence, efficiently utilizing the in hand energy resources of the sensor nodes for forwarding important data.

To solve these three issues namely hot-spot problem, delay minimization and QoS assurance, in this paper, Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed.

3.2. Network model and assumptions

WSNs consist of a large number of sensor nodes randomly deployed in a certain area (sensing field). After deployment, all the sensor nodes in the WSN will form group called clusters, and each cluster elects their CH in distributed manner using local information. Each CH collects sensor data from other nodes in the cluster and transfers the aggregated data to the next super node, which sends it to the static/mobile sink using multi-hop super-node communication (see Fig. 1). CH performs extra duty since it collects, aggregates, and relays data from/to its member nodes. To achieve balanced energy consumption, the role and responsibility as a CH is rotated over the time among the member nodes in the cluster. In the proposed EEQR protocol, the following assumptions are considered.

- WSN contains two types of nodes: normal node and few nodes equipped with extra energy resource, termed as *super-node*. Super-nodes are less in number than normal nodes.
- There is a static sink located at the center of the network. In addition, to static sink there is one mobile sink (GPS enabled), which can move across the whole WSN. Static/mobile sink has a sufficient energy resource. The sensor nodes (both super-nodes and normal nodes) are static and have no mobility. Only mobile sink having moving capability.

3.3. Description of the proposed protocol

Proposed has considered QoS and energy efficiency as the core design issue for data gathering in WSN. The following is the detailed explanation of the proposed EEQR protocol. The working of EEQR is explained by dividing it into to the following phases and sub-phases. It includes two main phases (Setup Phase and Steady Phase) and eight sub-phases (see Fig. 2). The first main phase is Setup Phase, which includes three sub-phases (initialization, route update, clustering). The second main phase is Steady Phase; it is divided into six sub-phases namely: Prioritization of data, forwarding data to CH/super node, forwarding data to static sink, forwarding queue weight to mobile sink, mobile sink movement decision, and mobile sink data gathering.

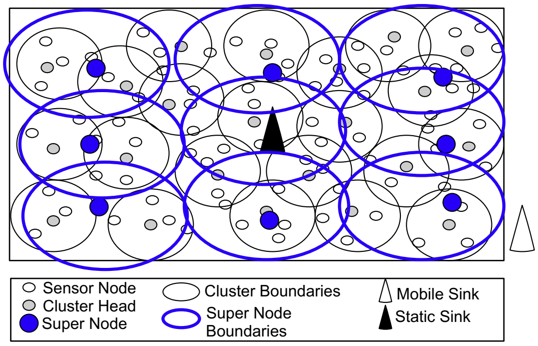


Fig. 1. A typical EEQR based data gathering in wireless sensor network.

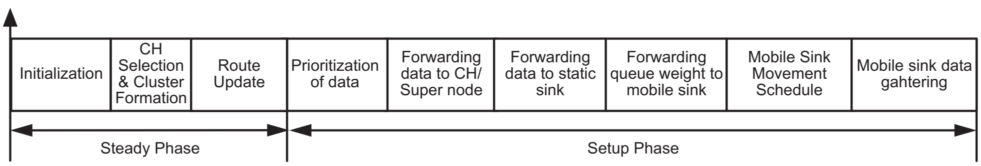


Fig. 2. EEQR operations.

3.3.1. Setup phase

Setup phase is further divided into three sub-phases namely: Initialization, clustering and route update.

3.3.1.1. Initialization. In this phase, after random deployment, each node determines its residual energy (i.e., battery power left) and its location in which it lies. The values like residual energy and distance to a BS are used as cost calculation in cluster formation and sink movement.

3.3.1.2. Clustering. In this phase, clustering [23,24] is done. All the nodes in a particular cluster choose a head node, known as cluster head (CH). The sensor nodes must associate themselves with some of these CHs and become members of a local group (cluster). Each group of nodes sends their data to the CH and then to the static/mobile sink. Details of how clustering is done is out of scope of this paper, interested reader may refer to our work in [23,24].

3.3.1.3. Route update. One hierarchy above the CH lays the super nodes which act as the local sink and gathers data from the CH. In route update phase, CH nodes forms multi-hop path of CHs to forward data to the super node. Afterwards, all the super nodes form multi-hop path of super nodes to forward data to a static sink.

Following is detail how route is maintained to the super node and to the static sink. Route update consists of two sub-phases: route update to super node and route update to static sink.

3.3.1.3.1. Route update to super node. To forward data to super node, CH nodes use multi-hop CH communication. To develop these routes, each super node generates route discovery message with hop count 0. It is broadcasted within the locality of these super nodes. Normal nodes are the recipients of this message, as these nodes (which could later become CH) will carry the received data to the super node. Upon receiving this broadcast message, a normal node updates its hop count value. Node changes it hop count value to new value, if the received hop counts value is less than the previous hop count value, otherwise, it retains the previous value. Each normal node increments the hop count and broadcasts the message to nodes in its communication range. In this way, a message arrives at each node following the desired minimum cost path. As a result, each normal node has minimum hop count path to their respective super-node. Once the hop count value is determined, this route information is later be used in inter-clustering communication.

3.3.1.3.2. Route update to static sink. In route update phase, static sink generates route discovery message with hop count 0. It is broadcasted throughout the network, where super nodes are the intended recipients of these messages as they are responsible for carrying data to a static sink. Upon receiving this broadcast message, a super node updates its hop count value. It changes its hop count value to a new value, if the received hop count value is less than the previous hop count value; otherwise, it retains the previous value. Each super-node increments the hop count and broadcasts the message to nodes in its communication range. In this way, a message arrives at each super-node following the desired minimum cost path. As a result, each super-node had obtained minimum hop count path to the static sink. Once the hop count value is determined, this route information is later be used in forwarding data to the static sink.

After route update phase, each normal node has minimum hop count path to the super node, and each super node has minimum hop count path to the static sink. Maintained route information will be used in later phases for inter-clustering communication

3.3.2. Steady phase

In steady phase, proposed protocol performs actual data gathering task. Steady phase can be further divided into following sub-phases.

3.3.2.1. Prioritization of data. In this phase, at each sensor node incoming traffic is prioritized based on message type and message content. Priorities assigned to the different messages are later used in the data forwarding decision, to maintain reasonable QoS for each traffic class. Prioritization of data is done at two levels.

3.3.2.1.1. Prioritization based on message type. Increasing interest in multimedia applications in WSN has made the QoS (quality of service) support an unavoidable task. A sensor node may have different types of sensor which gather different kinds of data. Based on message type, gathered sensed data could be divided into high priority real time traffic and low priority non-real time traffic. Both these types of data have different forwarding requirements. Real time traffic requires low latency and high reliability to facilitate immediate actions when required. Conversely, non-real time traffic can generally tolerate delay. Needs for both these types of traffic should be considered separately in taking data forwarding decision. For that, incoming traffic is prioritized based on their delay and bandwidth requirement and is divided into different traffic classes. Each traffic class depicts a distinct traffic type with a specific delay and bandwidth requirements. Traffic classes are assigned different priorities. In EEQR, to provide QoS, the incoming traffic is divided into three traffic classes namely: real time traffic, intermediate and non-real time traffic. Each traffic class is assigned different priorities: real time traffic highest priority, non-real time lowest priority and intermediate class priority lies between the two. According to their QoS requirements different priorities are assigned to these traffic classes and phenomenon of packet forwarding is done by these priorities.

3.3.2.1.2. Prioritization based on message content. The data sensed by a sensor node can have different levels of importance. It is desirable that sensor nodes scarce resource(s) should be spent in disseminating packets carrying more important information. The information content is determined through the importance of potential event need to be reported. Rule to determine information importance may vary depending upon the different applications. Once importance of the message has been defined, different priorities are assigned to different message based on the content of the packet. For instance, a high priority message relates to very high temperature in forest fire detection and requires a urgent action. Contrary to this a low message priority relates to low importance packet (for example packet carrying routine normal temperature). Intermediate packet refers to the message whose information content lies between the high priority and low priority messages. Accordingly based on the importance of the message content, packets are divided into three different message class (MC). MC 1 is the highest priority message, MC 2 is intermediate priority message and MC 3 is the lowest priority message.

To ensure fairness and to prevent the packet from low priority traffic class suffering long starvation, as case may be when the higher priority process keeps on arriving in the queue. The priority of the packet waiting in the queue increases by factor of 1 in start of every new time slot which helps to eliminate the obvious problem of starvation of the packets belonging to best effort and other low priority traffics. Hence, fairness is ensured to low priority packets in term of offering reasonable short delays.

At the end of this phase, at each sensor node different priorities are assigned to different types of traffic. A priority queue is maintained at each node, where packets are forwarded according to their priorities.

3.3.2.2. Forwarding data to CH/super node. When a data is sensed by the sensor node, which is need to be propagated to the sink. It is assigned the priority based on its importance according to its message type and content (as defined in previous phase). To handle these messages having different priorities, a priority queue is maintained at each of normal/CH/super node.

During this phase, each sensor node sends sensed data to their respective elected CH according to message priority. To do so, normal node checks its priority queue for the highest priority packet and forwards the highest priority packet to the CH. Similarly, priority queue is also maintained at each CH and highest priority packet is forwarded to the super node. As data has already been accumulated by super node from its CH, super node will calculate its Queue Weight (QW). It is the calculation of the weight of the queue, which is sum of the priority of all the packets in the queue. QW is used in later phase for deciding mobile sink movement.

3.3.2.3. Forwarding data to the static sink. Main shorting coming of the mobile sink approach is that, it maximizes end-to-end delay. As each sensor have to wait for mobile sink to comes in its vicinity to forward data. To avoid this drawback in EEQR, in addition to mobile sink, a static sink is used. In this phase, important data as dictated by its priority queue is send to the static sink to minimize its end-to-end delay. Whereas, delay tolerant data is send through the mobile sink, when mobile sink comes in super node's vicinity.

For forwarding data to the sink, protocols found in the literature have used a very simple technique, that is, each CH sends data to the next CH, and so on. Ultimately, nodes nearest to the sink send data directly to the sink. Whereas, with EEQR WSN operates with two types of nodes: normal nodes and super nodes. Normal nodes perform the normal task of sensing, whilst super node act as local sinks since they are having extra energy and communication capability. Data from normal nodes is collected by CH, which forward it to super nodes. Super nodes send the collected data to the sink using either multi-hop communication of super node or directly to the sink.

As movement of mobile sink, involves a delay which is not tolerable by the delay sensitive packets. Thus, to avoid this drawback of mobile sink, in EEQR forwarding decision is taken on super node. Forwarding decision involve based on the priority queue status, whether super node should send data to the static sink or it should wait for mobile sink to visit its vicinity.

Following is description of the forwarding decision; it includes explanation of decision variables involved and detail of actual forwarding decision.

3.3.2.3.1. Decision variables. The description of these decision variable used for determining whether to send data to static or wait for mobile sink is as under:

Queue Weight (QW): It is the calculation of the weight of the queue, which is sum of the priorities of all the packets in the queue.

Max Queue Weight (MQW): Since the arrival rate of packets belonging to different traffic classes can be random, hence taking decision on the basis of queue length can affect QoS of packets belonging to different traffic classes. To ensure QoS in forwarding decision MQW is used. MQW is the maximum threshold value of the QW, after which data should sent to the static sink, to satisfy delay constrained requirements of data.

3.3.2.3.2. Switching decision. Decision whether to send the data to the static sink or wait for the mobile sink is taken when following conditions becomes true:

$$\textit{Queue Weight of super node is greater than Maximum Queue Weight } (MQW)$$

i.e., when QW becomes greater than MQW data is send to static sink to minimize delay.

After forwarding decision, if data is need to be send to the static sink, data is forwarded along multi-hop super nodes path established in route update phase.

3.3.2.4. Forwarding queue weight to the mobile sink. At the end of first and every subsequent cycle of mobile sink movement across the whole WSN, mobile sink send the request for queue weight across the WSN. Super nodes are the intended receipt of this message. Each super node upon the receipt of this message from the mobile sink calculates its QW and sends the required information to the mobile sink. Later, mobile sink will devise its schedule based on this QW.

3.3.2.5. Sink movement schedule. QW information of all the super nodes from the whole network is already been received by the mobile sink in the previous phase. In this phase, mobile sink will prepare its schedule to move across the whole WSN to collect data from the available super nodes. Movement of the mobile sink in first movement cycle is based on predefined position. But to provide QoS and ensure balance used of energy, movement of mobile sink in second and subsequent cycles is based on the residual energy and QW of super nodes in the network.

3.3.2.5.1. Devising movement schedule. In devising movement schedule, to achieve energy efficiency and QoS, mobile sink favors the super node with higher energy and higher queue weight. Mobile sink arrange the movement plan and visit each super node based on their queue weight and residual from highest to the lowest. It helps to achieve QoS and prolonging the network lifetime, as super nodes in mobile sink vicinity are always be the high energy nodes. As these nodes has to relay the data of the nodes away from the mobile sink. Furthermore, with regular sink movement nodes near to the sink changes with each movement. Thus, chances of formation of hop spot problem or energy hole is minimized. Algorithm 1 states the sink movement schedule algorithm. Afterwards, mobile sink disseminates the movement plan to all the nodes in WSN.

Algorithm 1: Sink Movement Schedule Algorithm

Input: Queue Weight and residual energy of super nodes.
Output: Sink movement schedule
QW : *Queue Weight*
Begin
1. **if** movement cycle is first **then**
2. **move** in the network according to the predefined locations.
3. **else**
4. **sort** the QW and residual energy of different super nodes in descending order.
5. **arrange** the movement schedule for each super node based on their queue weight and residual from highest to the lowest.
6. **broadcast** the movement schedule across the whole WSN.
7. **end if**
End

3.3.2.5.2. Advertising mobile sink movement schedule. Once decided mobile sink advertise the movement schedule across the whole WSN. Super nodes are the intended receipt of this advertisement message. Upon the receipt of the mobile sink movement advertisement message, super node accordingly arrange sleep/wake schedule, thus, at the time of visit of the mobile sink, super node will be in wake state.

At the end of each cycle of movement across the whole WSN, mobile sink collect the QW from the super node and devise new movement schedule.

3.3.2.6. Mobile sink data gathering. In this phase, mobile sink move across the whole WSN to gather the sensed data from the super nodes. The schedule how mobile sink visit all the super node is already been defined in the previous phase. As per movement schedule, mobile sink visit each super node, do the advertisement, define the TDMA schedule for super nodes, and gather the data from super node. Following is description of the steps involved in this phase.

3.3.2.6.1. Mobile sink advertisement and super node registration. Mobile sink when reaches any new place during its mobility, it need to inform the super nodes in its neighborhood about its presence, thus, nodes in its neighborhood can send the sensed data to the sink. To do so, mobile sink when reaches any new destination broadcast beacon advertisement message. It contains the location information of the mobile sink and information of mobile sink moving velocity V. All the super nodes which receive mobile sink beacon message, responds by sending registration message to mobile sink. If super node has already sent its data to the static sink or has already send data to the mobile sink in some of its previous movement in the current cycle, super node will ignore this message. Otherwise, super node respond to the mobile sink by sending super nod registration $SN_{register}$ request to the mobile sink. The mobile sink waits for time interval (communication delay) to receive the SH_{ack} from the mobile sink. Following Algorithm 2 is used for mobile sink advertisement and super node registration.

Algorithm 2: Mobile sink advertisement and super node registration Algorithm

Input: mobile sink advertisement
Output: super node registration

T_i : *Time period based on communication delay*
$SN_{register}$: *Super node Announcement*
SN_{ack} : *Super node Acknowledgment*.

Begin
1. Mobile sink sends the beacon message and sets the time interval *'Ti'* based on the communication delay
2. Super-node receives the beacon message from the mobile sink
3. **if** super node has data to send **then**
4. **send** $SN_{register}$ to the mobile sink
5. **set** the time interval 'T_i' based on the communication delay and wait for SN_{ack}
6. **end if**
7. **if** mobile sink receives message from super-node within the time period 'T_i' **then**
8. **if** message received is $SN_{register}$ **then**
9. **send** SN_{ack} message to that node
10. **include** the node in the registered super-node list.
11. **end if**
12. else
13. **move** the mobile sink to the next place, based on the sink movement schedule defined by algorithm 1.
14. end if
End

3.3.2.6.2. TDMA scheduling. Once mobile sink has registered with all the super node in its current neighborhood. Mobile sink assign the time slots to all the registered super node, i.e., slots when the registered super node nodes can send the sensed data to the mobile sink. Consequently, in this phase mobile sink devise and send the TDMA schedule to the registered super node's using the following Algorithm 3.

Algorithm 3: TDMA schedule Algorithm

Input: Registered super-node list.
Output: Super-node TDMA schedule.
TDMA : Time division multiple access
Begin
1. Mobile sink checks the registered super-node list defined by algorithm 2 and arranges the time slot for the registered super-nodes accordingly.
2. **send** the super-node *TDMA* schedule T*DMA* to the registered super-nodes.
3. **wait** for the sensed data from the registered super-nodes
4. **receive** the sensed data from the super-nodes in the assigned time slots.
End

3.3.2.6.3. Forwarding data to mobile sink. In this phase, each super node use single hop or multi-hop communication to forward sensed data to the mobile sink (see Fig. 3). It involves how super nodes send sensed data to mobile sink in allocated time slot. Thus, for agreed TDMA time slot (discussed in previous section) super node sends the sensed data to the mobile sink. For forwarding the packets super node checks its priority queue and forwards the highest priority packet to the mobile sink. The process of forwarding the highest priority packets continues when any of the condition mentioned in "Sink Movement Decision" phase becomes true. When any of switching condition becomes true, mobile sink move to the next destination and repeat the same process of forwarding the packet continues at next position. To avoid long delays, super node increment the priority of the packet waiting in the super node queue by 1 at the end of every time slot. With sensed data super node also piggy back the residual energy information to the mobile sink. At mobile sink this residual energy information is maintained in Super Node Residual Energy Table (SNRET). Residual energy information is used in next phase in making sink movement decision.

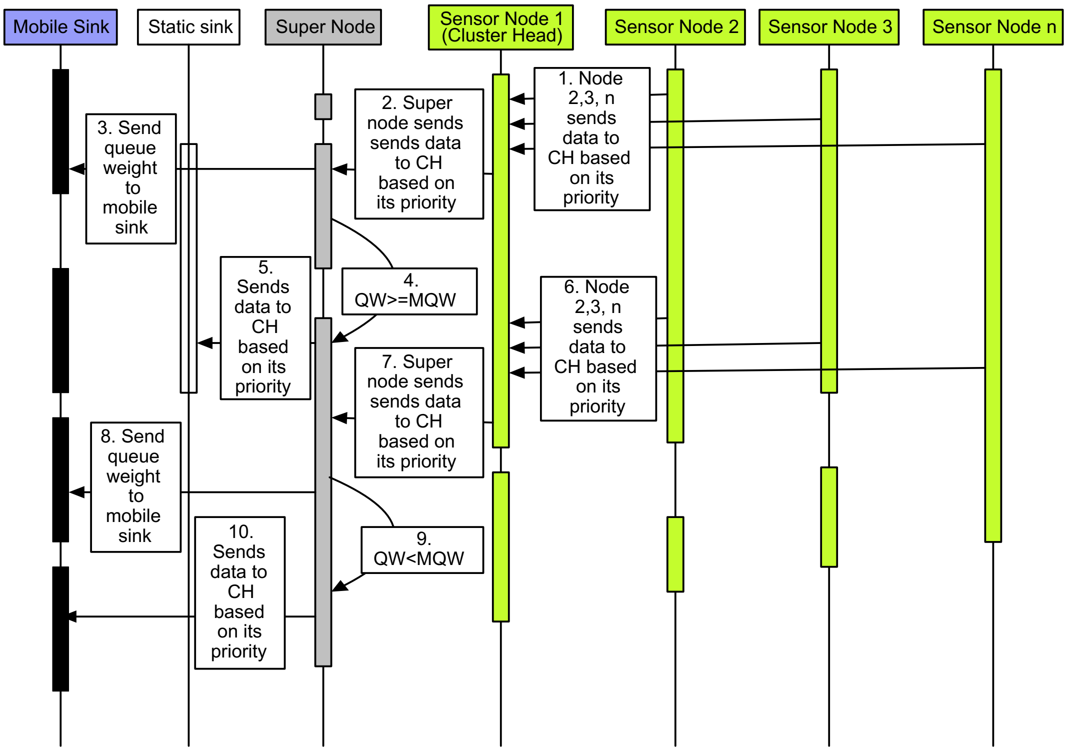


Fig. 3. An event diagram for the interaction between sensor nodes, CH and BS during simulation.

3.3.2.6.4. Sink next movement. Schedule how to visit different super nodes in the network is already been defined in phase "Sink Movement Decision". In this phase mobile sink takes the decision when to switch/move to the next super node.

Following is the description of decision variables involved in the devising mobile sink next movement decision and detail of how movement/switching decision is taken.

a. Decision variables

Decision variables are used for determining movement schedule of mobile sink and time instants when the mobile sink should switch from one super node to the other during its movement. The description of these decision variables is as under:

1. *Predictability Factor (P)*: This factor is use in calculating Time Commitment (TC). It is calculated by estimating average packet length of the traffic in the queue for a super node.
2. *Time commitment (TC)*: This variable, set the minimum interval mobile sink will spend outside any super node. It is calculated on the basis of the queue length and Predictability factor (P) of the other super node, i.e., provide estimate of time to exhaust the outgoing queue. It limits the mobile sink not to address a current super node indefinitely and switch to next super node whose TC expired.
3. *Max time-share (MTS)*: This is the maximum time a mobile sink can spend with a super node. It is the limit the mobile sink not to address a current super node indefinitely and switch to super node when MTS expires.

b. Switching decision

Decision of when to switch the mobile sink to the next super node is based on the following condition using the above mentioned decision parameter. Consider a mobile sink with $X_1, X_2, \ldots, X_n$ are its super node points, where it stays across the network, X_1 is the first super node to be visited and X_n is last to be visited. Suppose X_1 and X_2 be any consecutive super node points, mobile sink is at X_1 and X_2 be the next point to be visited. According to proposed protocol, the mobile sink will move from X_1 to X_2 when any of the following conditions becomes true:

1. *Time in X_1 has become greater than Maximum Time Share (MTS).*
2. *Time Commitment (TC) for super node X_2 becomes 0.*
3. *Queue Length for super node X_1 becomes 0.*
4. *Queue Weight of super node X_2 greater than Maximum Queue Weight (MQW).*

If any of the above condition becomes true, then mobile sink before moving to the X_2 calculates its TC for X_1 which will be:

$$Time\ commitment\ (TC) = \sum_{i=1}^{n}(Queue\ Length\ of\ supernode\ X_i \times Predictability\ Fuunction\ (P)\ of\ super\ node\ X_i) \tag{1}$$

During its movement across the network when mobile sink reaches the last movement place, it sends the cycle completion message across the whole network. All the super node which receive this message and respond back by sending their respective queue weight. Afterwards, steps from phase IV "Forwarding queue weights to the mobile sink" (explained above) is repeated for the next and preceding mobile sink movements for each movement cycle.

4. Simulations and results

Based on the developed system model, simulations are carried out using OMNet++[1] to evaluate the performance of the proposed EEQR protocol. Performance of proposed EEQR protocol is compared with the two contemporary static sink and mobile sink. Experimental parameters, such as energy per packet, average delay per packet, average packet loss, throughput, and coverage lifetime are used to evaluate the EEQR performance.

The following are the details of the simulation setup, energy model, and discussion of the results.

4.1. Simulation setup

Simulations were conducted in the sensing area of $200 \times 200\ m^2$ and number of sensor nodes varied from 20 to 240 for different experiments. Sensor nodes were randomly deployed, and the random deployment is achieved by choosing (x, y) locations based on a uniform distribution. One sink is fixed and located at the center of the network and the other sink is mobile which moves in the network. The simulations were conducted with communication range which is equal to double of their sensing range. The simulation parameters are given in Table 1.

4.2. Energy model

It is assumed that the sensor nodes have the ability to adjust their transmission power according to the distance of the receiving node. The energy model presented in [25] is adopted here. The amount of energy consumed for transmission E_{TX} of an l-bit message over a distance is given by

$$E_{Tx} = \begin{cases} l \cdot E_{elect} + l \cdot \varepsilon_{fs} \cdot d^2 & for\ 0 \leqslant d \leqslant d_{crossover} \\ l \cdot E_{elect} + l \cdot \varepsilon_{mp} \cdot d^4 & for\ 0 \geqslant d_{crossover} \end{cases} \tag{2}$$

where E_{elect} is the amount of energy consumed in electronics, ε_{fs} is constant for free space propagation and is the energy consumed in an amplifier when transmitting at distance shorter than $d_{crossover}$, and ε_{mp} is constant for multi-path propagation and is the amplifier energy consume in an amplifier when transmission at distance greater the $d_{crossover}$. The energy expended in receiving l-bit message is given as

$$E_{Rx} = l\ E_{elect} \tag{3}$$

4.3. Results and discussion

Performance of EEQR is evaluated and compared with contemporary static sink and mobile sink strategies. Metrics used for performance comparison are average energy per packet, network lifetime, throughput, average delay per packet, packet loss ratio and coverage lifetime. Findings of our experiments are as under.

4.3.1. Average energy per packet

Average energy per packet is the measure of energy spent in forwarding a packet to the base station.

It is the indicator of the life time optimization achieved by the protocols. In this experiment, average energy per packet is measured by varying number of sensor nodes (20–240).

Average energy consumption per packet for the proposed protocol (see Fig. 4) is less than static sink. Reason is that in static sink, nodes near to the static sink remains same and they have to relay the data on behalf of the nodes away from the static sink. It results in formation of hotspot/energy hole near the sink, hence, energy per packet in static sink is greater. Conversely, in proposed protocol combination of static and mobile sink approach is used, added by the traffic prioritization mechanism by which packet are relayed either to the static sink or mobile based on its QoS requirement. In proposed protocol by virtue of mobile sink energy hole problem is minimal, as nodes near to the sink are high energy node and they change over time with mobile sink movement. It results in balance used of energy across the whole sensor network. Addi-

[1] http://sce.uhcl.edu/yang/public/download/OMNET++.pdf.

Table 1
Simulation parameters for EEQR.

Simulation parameter	Acronym	Value
1. Network		
Network area/size	S	200×200 m^2
Static sink location	(x,y)	(100,100)
Number of nodes	N	20–240 nodes
Node radio range	R_{sense}	15 m
Communication range	R_{comm}	30 m
Node distribution		Node are randomly deployed
Simulation time	S_{time}	900 s
Number of trails	N_t	20
2. Battery		
Initial energy(J)	E_I	1 J
Dead nodes(J)	E_D	<0.1 J
3. Radio		
Energy spent in transmitter/receiver electronics (pJ/bit	E_{elec}	50 nJ/b
Constant for free space propagation (pJ/bit/m^2)/	ε_{fs}	10 nJ/b
Constant for multi path propagation eamp(pJ/bit/m^4)	ε_{mp}	0.003 pJ/bit/m^4
Data aggregation/fusion energy	E_{DA}	5 nJ/bit/signal
4. Application		
Data packet size	P_{dsize}	500 bytes
Control packet size	P_{csize}	25 bytes
Packet rate	P_{rate}	1 packet/s
Period of each round	PR_r	5 s

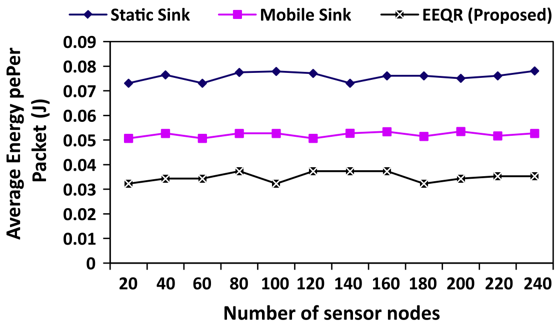


Fig. 4. Average energy per packet under different number of sensor nodes.

tionally, in proposed protocol static sink is used for forwarding only the delay sensitive data which minimize possibility of hotspot formation. Energy efficiency in proposed protocol is supplemented by use of super node, which also minimizes the inflow of data towards the node near the static. As only super nodes communicate the data to the static sink on behalf of neighboring nodes. Thus, proposed protocol improves the life time of the WSN as compare to static sink.

Mobile sink protocol has also got greater average energy per packet than proposed protocol. Although in mobile sink approach, due to sink movement big hotspot is not formed around the nodes as the case in static sink. But still as in mobile sink approach, nodes near the sink at each stay point of the mobile sink remain same throughout the network lifetime. These nodes have to repeatedly relay the data of the nodes away from mobile sink at that stay point. Thus, mobile sink is vulnerable to mini energy hole and mini- hotspot problem around the stay points of mobile sink. Hence, energy per packet of the mobile sink approach is greater than proposed protocol. Whereas in proposed protocol, combination of static and mobile sink is used. It results in balanced used of sensor node energy across the whole network. Furthermore, energy saving is supplemented by the traffic prioritization mechanism and use of super nodes. Hence, average energy per packet of the proposed protocol is less than the mobile sink approach.

4.3.2. Network lifetime

Network lifetime is time how long the percentage of nodes remains alive. It is represented by $T_{n\%}$ where n is the number of alive node. Fig. 5 shows the network lifetime corresponding to three protocols.

It can be observed that proposed protocol has longest $T_{100\%}$ followed by mobile sink, and static sink approach has the shortest network lifetime. Indicating that proposed protocol improves the life time of WSN as compare to static sink and mobile sink approaches.

Proposed protocol has greater lifetime than the static sink approach, because in static sink all the nodes relay their data through the same nodes which are near the sink. Over the time, these nodes expire forming a hotspot/energy hole near the

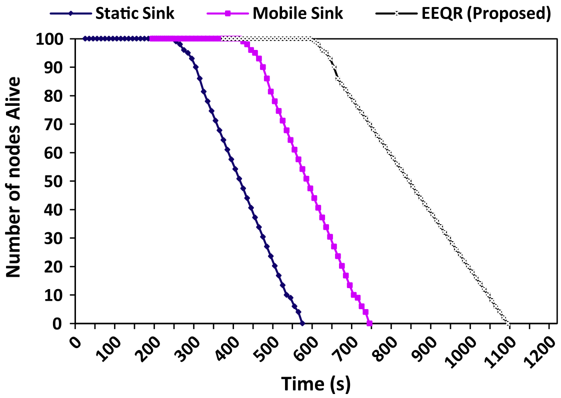


Fig. 5. Network lifetime.

static sink which significantly limit the network lifetime. Whereas, in proposed protocol, mobile sink is used in addition to the static sink, which move across the network to gather data. By doing so, nodes near the mobile sink changes with every mobile sink movement. Hence, all the nodes use their energy in balanced way and no energy hole is formed, which prolongs the network lifetime. Furthermore, in proposed protocol the balanced use of sensor node energy is complemented by use of prioritization mechanism by which traffic is routed to the appropriate sink (static or mobile) based on its QoS requirement, which contribute in maximizing network lifetime.

Mobile sink approach has smaller network lifetime than proposed protocol. Mobile sink approaches result in formation of mini hotspot or energy hole, which minimizes the network lifetime, not as adverse as static sink approach but still affects the network lifetime. Whereas, in proposed protocol data forwarding is neither solely relaying on static sink nor on mobile sink, rather a combination of two is used which ensure balanced use of energy of the nodes across the network, result in increasing the network lifetime.

4.3.3. Throughput (packets per second)

Throughput refers to the number of packets received per second at the sink. In this experiment, throughput is measured in terms of packets per second by varying the number of sensor from 20 to 220. Fig. 6, shows the simulation results for all the three protocol compared (static sink, mobile sink and proposed protocol).

It can be observed that proposed protocol outperforms static sink and mobile sink approaches, in terms of throughput. Reason is that, in static sink nodes near the sink remain same and is vulnerable to energy hole and hotspot problem. Whereas in proposed protocol energy hole issue is addressed by using mobile sink, as the immediate neighbor of the sink changes due to regular sink movement. Consequently, the hotspot problem is minimized and more packets can be forwarded to the BS (throughput).

Mobile sink approaches have also got less throughput than proposed protocol because in mobile sink all the nodes have to wait for the mobile sink to come in its vicinity for data forwarding. In the process, some of the packet expire their time to live (TTL) and cannot be forwarded to the mobile sink. It limits the number of packets received by the mobile sink. Whereas in proposed protocol as static sink is employed in addition to the mobile sink and prioritization mechanism is set in place to take decision to forward the data according to its QoS requirement to the static sink or mobile sink. Delay constraint message in terms of traffic type or content is sent to the static sink and delay tolerant packets are sent to the mobile sink. It ultimately

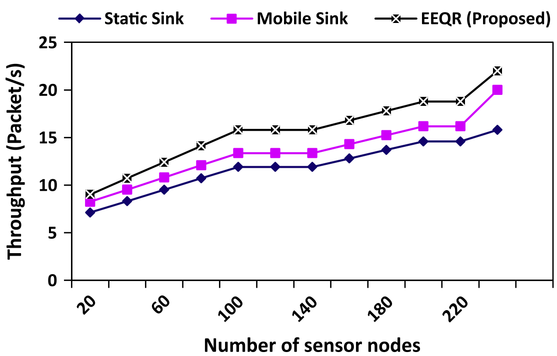


Fig. 6. Throughput (packet per second) under different number of sensor nodes.

increases the throughput as by use of static sink and prioritization mechanism more packets can make their way to the sink, which otherwise could not be forwarded in mobile sink approach. Furthermore, in proposed protocol combination of static and mobile sink, avoids the mini hotspot which generally form near the mobile sink stay points in the network in mobile sink approach. In mobile sink approach, due to mini hotspot/energy hole phenomenon reduces the number of packets forwarded to the mobile sink at a particular stay point. Whereas in proposed protocol, two channels static sink and mobile sink are available to the sensor nodes for data forwarding, which increases number of packets forwarded, that's why proposed protocol has better throughput than mobile sink approach. Furthermore, it can be seen from the Fig. 6 that proposed protocol is more scalable and performs better than other protocols with bigger network size.

4.3.4. Average delay per packet

Delay is referred as the time span between the packet sent from a sensor node and packet received at the BS. Delay values are measured by changing the number of sensor nodes from 20 to 240.

As shown in Fig. 7, the average delay experienced by the proposed protocol is the least, while static sink is the second and mobile sink has the worst delay time.

Static sink approach has got greater delay than proposed protocol, because in static sink approach all nodes have to relay their data all the way to BS using multi-hop communication, and on the way it involves many relay nodes to reach the BS. Considering the local traffic at each node, sensed data have to wait for some time at each node to get attention, as well as the time required to forward the data to the next node or BS. Additionally, static sink approach has got no prioritization mechanism which can treat the incoming traffic based on its QoS requirement. It makes static sink prone to longer delay. Whereas in proposed protocol, combination of static and mobile sink are used and prioritization of packet is done based on its QoS requirement. Delay sensitive packets are send either to static sink and delay tolerant to the mobile sink based on the QoS (delay) requirement of the packet. It makes delay of the proposed protocol less than the static sink approach.

Mobile sink approach has average delay less than the proposed protocol. Reason is that, in mobile sink approach, nodes have to wait for the mobile sink to come in its vicinity to forward the data. It results in increasing the delay especially for the group of nodes which are visited last by the mobile sink. In proposed protocol, every node is supposed to send their data to the local sink (super-node) in their vicinity, which means that each packet did not have to wait long when it is to be propagated to the static sink or mobile sink. Furthermore, by virtue of prioritization mechanism the packets are send either to static sink or mobile sink based on QoS requirement of the traffic type and content. That is why proposed protocol has less delay than mobile sink approach.

Fig. 7 shows that as when the number of nodes increases, the performance difference between proposed protocol and other two approaches (static sink and mobile sink) also increases. For proposed protocol, the performance remains the same for the increased number of nodes, since super nodes and static sink are always been there to be used as local sink, whatever may be size of the network. In this way, increasing the node number has no performance deterioration effect on proposed protocol. It suggests that the proposed protocol is more scalable than mobile sink and static sink protocols.

4.3.5. Packet lost ratio (%)

Packet lost ratio refers to the percentage of the packets that could not reach the BS, i.e.

$$\text{Packet Lost Ratio} = \frac{\textit{Total number packets not received at the BS}}{\textit{Total number packets send by all the sensor nodes}} \tag{4}$$

Fig. 8 shows the measurement of packet lost ratio for the three protocols with varying number of sensor nodes (20–240). It is clear from Fig. 8 that the proposed protocol has far less packet lost ratio as compared to static sink and mobile sink.

Proposed protocol has less packet lost ratio, than the static sink approach, because in static sink, a node needs to send data all the way to an intended BS using multi-hop communication. It involves many relay nodes before data reaches the static

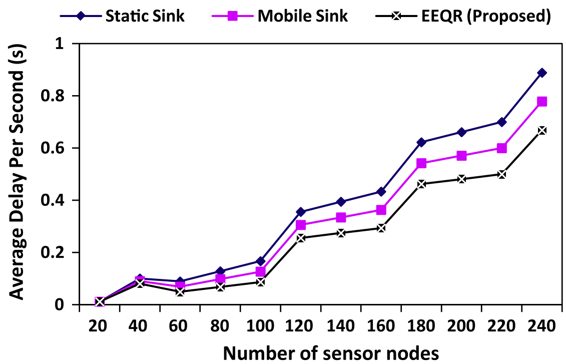


Fig. 7. Average delay per packet for different number of sensor nodes.

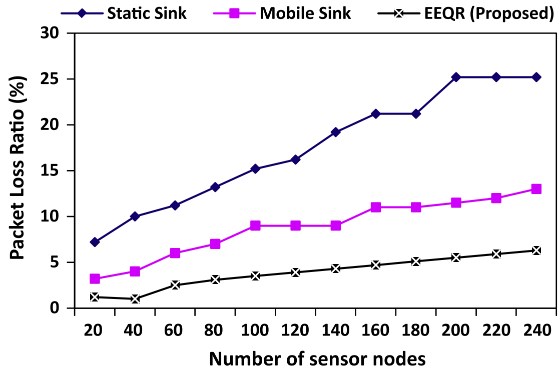


Fig. 8. Packet lost ratio for different number of sensor nodes.

sink. It makes static sink more vulnerable to packet loss, thus reducing transmission reliability. Whereas, in proposed protocol, packets are forwarded either to the static sink or mobile sink, according to the proposed underlying prioritization mechanism. Priority mechanism forwards the packets according to their QoS requirement based on traffic content and type. It decreases the packet lost ratio, as packet are treated according to differentiated QoS requirements and thus, more packets manage to reach the sink.

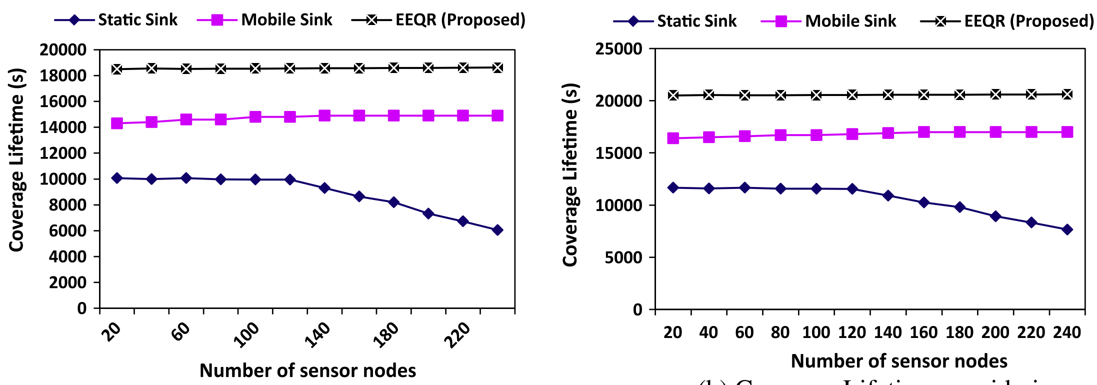
Mobile sink approach has also got packet lost ratio greater than the proposed protocol. Reason is that, in mobile sink approach data at any particular node has to wait for the mobile sink to come in it vicinity to forward data. In the process, packets may expire their time to live (TTL), hence could not be delivered to the mobile sink. Whereas, in proposed protocol, static sink is used in addition to the mobile sink, it increases the successful delivery of the packets. As now packet has two channels to send the data, according to the message priority based on its QoS requirement. Additionally, at each node, CH and super node prioritization of data is done based on the message content and type. Forwarding data to static or mobile sink is also based upon the QoS requirement of the data. Hence, proposed protocol has less packet loss ratio than mobile sink approach. Furthermore, in proposed protocol, nodes are required to forward their data to a local sink (a super-node). The super-node will send the data to static/mobile sink via multi-hop super-node communications. Hence, proposed protocol involves far less relay nodes, which makes it less prone to packet loss. As a result, proposed protocol outperformed the other two protocols in terms of packet lost ratio.

4.3.6. Coverage lifetime

Coverage lifetime is referred as the time network is able to preserve 100% or over 90% coverage of the whole sensing area of the network. As a generalization, coverage of less than this percentage is not tolerable and can be regarded as failure to the whole network.

In this experiment, number of nodes is varied from 20 to 240, and coverage lifetime (100%, 90%) is measured. Fig. 9(a) provides coverage lifetime for 100% coverage area, while Fig. 9(b) depicts coverage lifetime for 90% coverage area.

From Fig. 9(a) and (b), it can be observed that proposed outperformed static sink and mobile sink in terms of coverage lifetime in both cases of 100% and 90% coverage. Proposed protocol has coverage lifetime better than the static sink approach,



(a) Coverage Lifetime considering 100% coverage

(b) Coverage Lifetime considering 90% coverage

Fig. 9. Coverage lifetime for different number of sensor nodes: (a) 100% coverage and (b) 90% coverage.

Table 2
Summary of performance comparison between static sink, mobile sink and proposed protocol.

Protocols compared (240 nodes)	Average energy per packet (J)	Average delay per Sec (s)	Packet loss ratio (%)	Throughput (packet/s)	Coverage lifetime (s) (100%)
EEQR (the proposed protocol)	0.0453	0.668	6.3	22	18,617
mobile sink	0.05271	0.778	13	20	14,900
Static sink	0.0861330	0.888	25.2	15.8	6050

because in static sink approach nodes have to relay the data all the way to the BS. Consequently, nodes near to the sink have to relay the data on behalf of entire network. It makes nodes near to the static sink die earlier, resulting in creation of coverage hole. It considerably decreases the coverage lifetime. Whereas, in proposed protocol, use of mobile sink avoids the formation of coverage hole near the sink. As with the mobility of mobile sink, nodes near to the sink changes resulting in balanced use of nodes energy across the whole network. Furthermore, in proposed protocol, use of static and mobile sink distribute traffic between static and mobile sink based on its distinct QoS requirement, hence ensuring balanced use of energy across the whole network. Additionally, traffic prioritization mechanism ensures the use of sensor node energy for relaying important data. Using these heuristics, proposed protocol denies formation of any energy or coverage hole and ultimately increases coverage lifetime.

Proposed protocol has coverage lifetime better than the mobile sink approach. The reason is that in mobile sink approach, mini hotspots are formed near the stay points of the mobile sink. Whereas, in proposed protocol this mini-hotspots/energy holes are denied by using static sink in addition to mobile sink. It results balanced use of energy of all sensor nodes in the network. Ultimately, no coverage hole is formed results in increasing the coverage lifetime of the network when compared with mobile sink approach. As a result, proposed protocol outperformed the other two protocols in terms of coverage lifetime.

5. Conclusions

An energy-efficient and QoS aware routing technique for WSN is proposed, called Energy Efficient and QoS aware Routing (EEQR) protocol for Clustered Wireless Sensor Network is proposed in this paper. Using simulation, EEQR protocol results are compared against the contemporary static sink and mobile sink protocols. Simulation results demonstrated that EEQR has achieved significant energy saving and enhanced the network lifetime. The use of combination of static and mobile and the inclusion of prioritization mechanism based on traffic content and type in EEQR have helped the sensor nodes to disseminate their energy in a much more balanced rate, decrease delay and provide QoS to all type of traffics. The results demonstrated that EEQR is effective in improving QoS parameters, such as average delay, packet loss ratio, and throughput, when compared with static sink and mobile sink approaches. Table 2 summarized the key findings of this paper.

For future work, the plan is to extend the simulation experiments to consider other parameters and scenarios like fault tolerance and impact of data aggregation. It is also anticipated that further improvement in energy efficiency can be achieved by considering the concept of limited mobility of the sensor nodes. Furthermore, it will be interesting future direction to evaluate EEQR in WSN with mobile sink following different mobility models.

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