Energy Efficient QoS Routing in Multi-Sink Wireless Multimedia Sensor Networks

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Summary
In this paper we propose a multi-sink wireless sensor network architecture where the network is partitioned into clusters with multiple sinks to increase the manageability of the network and also to reduce the energy dissipation at each node. All the sources in a cluster were assigned to send the video and imaging data to the sink designated to that particular cluster in order to ensure efficient usage of the sensors and effective access to the gathered information. The proposed EEQR protocol ensures end-to-end delay requirement of real time data, as well as maximizes the throughput of non real-time data by transmitting the gathered data to the appropriate sink. Simulation results have demonstrated the effectiveness of our approach for different metrics.

Key words:
Quality of service, Multimedia data, Wireless sensor network, Classifier, multi-sink..

1. Introduction

Wireless Sensor Networks (WSN) is the network comprised of a large number of nodes with sensing and routing capabilities [1]. The WSN have nodes with severe energy constraints, variable quality links, and low data-rate. Due to the availability of the low-cost cameras, microphones, and other sensors producing multimedia data such as images, audio, video have made it possible to gather information rich multimedia data from the physical world which will enhance the performance of target tracking, environmental monitoring, industrial process control and time critical applications, etc. in WSN and the resulting network can be termed as Wireless Multimedia Sensor Networks (WMSNs). The unique characteristics of multimedia data and design issues of WMSN are discussed in [2], [3]. The existing applications of WSN such as real time target tracking in battle environments, emergent event triggering in monitoring applications etc. are extended to video surveillance and notification, video and computer assistance in video-assisted living and healthcare to get improved performance. The stringent requirements of real-time multimedia applications include end-to-end delay; bandwidth and packet loss. Managing real-time data requires both energy efficiency and Quality of Service (QoS) assurance in order to ensure efficient usage of sensor resources and correctness of the collected information. Communication protocols for WMSN must therefore be specially designed to operate efficiently under these constraints. In order to satisfy the energy constraints and the QoS requirements for the WMSNs, clustering has been a common and active approach to organize sensor networks into clusters [4]. The range of the sensors' radio is in general quite short when compared to the network size of a typical WSN covering a large geographical area. Multi-hop routing is preferably used for the transport of the sensed data to sinks because most of the nodes would be far away from the sink and thus requires many hops to reach the sink [1] and as the path length becomes longer, the more energy is dissipated. As a result, response times become excessive and the lifetime of the WSN becomes very short. To save energy, a single-sink model is not scalable for large-scale WSNs. In fact, with increase in the number of sensor nodes, the information collected at the single sink some times might become excessive with respect to its communication capacity Recently, due to the scalability problems of single-sink network architectures made it to evolve towards scenarios with multiple sinks to achieve shorter paths and where nodes must form efficient data gathering trees and select the best sink to send these data [5], [6]. Multi-sink networks can remarkably reduce the mean distance between nodes and sink, basically resulting in energy saving and longer lifetime. The main focus in this paper is not only to develop energy efficient routing providing service differentiation for multimedia real-time data but to investigate use of multiple sinks in clustered WSN which improves the network lifetime. We compare the performance improvement using proposed protocol with multi-sink over the single sink model considering the impact on varying buffer size, minimum hop count, and minimum end to end delay.

The rest of the paper is organized as follows. The Section II related work is reviewed. Section III describes about the system architecture of multi sink WMSN and explains about the proposed protocol. Section IV explains performance results. Section V presents the conclusions.

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2. Related Work

A good survey of routing techniques in WSN is provided in [7]. In general, depending on the Network Structure, routing in WSNs can be classified as Flat based, Hierarchical based and Location based routing. In Flat-based routing all nodes are typically assigned equal roles or functionality. In Hierarchical-Based Routing, the nodes will play different roles in the network and in Location-Based Routing sensor nodes' positions are exploited to route data in the network. Many other routing protocols have been proposed, however we limit the discussion to hierarchical routing protocols as the proposed routing scheme follows the specific features of this category of protocols

2.1 Hierarchical Based Routing Protocols

This section discusses energy efficient hierarchical routing protocols proposed in literature. Hierarchical-Based Routing improves energy utilization and scalability among the sensor nodes in a large scale network which covers a large geographical area with large number of nodes. These protocols divide the network into number of clusters and each cluster is with a Cluster Head (CH) responsible for communication between the nodes and the sink. In the literature many cluster based routing protocols have been proposed for energy saving.

Low Energy Adaptive Clustering Hierarchy (LEACH) [8] is a clustering-based protocol uses randomized rotation of the cluster-heads so the high energy dissipation in communicating with the base station is spread to all sensor nodes and hence evenly distributing the energy load among the sensor nodes in a network. While there are advantages to using distributed cluster formation algorithm, LEACH offers no guarantee about the placement and/or number of cluster head nodes. Since the clusters are adaptive, obtaining a poor clustering set-up during a given round will not greatly affect overall performance. In order to improve the quality of elected cluster head, LEACH-C [9] was proposed using a centralized clustering algorithm in which the base station adopts simulated annealing algorithm [10] to solve the NP-hard problem of finding optimal clusters [11] so as to evenly distribute the network energy consumption. Authors in [12] propose a centralized clustering algorithm, Base Station Controlled Dynamic Clustering Protocol to better organize clusters. The algorithm consists of setup and communication phases. During the set up phase each node sends the value of its current remaining energy to the base station. The base station will determine the nodes that have more than average remaining energy. Out of these nodes a specified number will become CHs. The high burden of being CH is distributed by repeating this process. After the CH set has been determined, the base station will split the network into two clusters, selecting two nodes (from the CH set) with the greatest separating distance to be the CH of each cluster. Nodes will be allocated to each cluster based on distance before cluster balancing is applied to attain approximately the same number of nodes in each cluster. Each cluster is split and this process is continued until the required number of CHs is allocated. Authors in [13] consider optimizing cluster formation by calculating the total square of the distances between the CH and all the nodes that the CH can support for different cluster formations. Clusters are selected based on the minimum total square of the distances between the CH and its member nodes. Authors in [14] propose an asynchronous clustering protocol called EEAC (Energy-Efficient Asynchronous Clustering), for event-driven sensor networks. The asynchrony means cluster head can autonomously decide the clustering occasions according to a certain probability, rather than deterministically. This probability lies on cluster head’s data transmission rates and residual energy. EEAC provides QoS guarantee and energy-efficient features. In [15] authors proposed a novel load-balanced and energy-efficient routing protocol. Maximum Energy cluster head (MECH) outperforms LEACH by a more balanced cluster distribution and by reducing the non-uniform cluster topology. It uses the number of cluster members and radio range to construct a cluster in a certain area. It also improves the distance of cluster-head communications with base station via a hierarchical tree. MECH faces synchronization problem. It is difficult to make thousands of nodes to time synchronization.

2.2 Multi-Sink

Many new protocols are specifically designed for WSNs where energy awareness is an essential consideration. The large data traffic generated by the large number of sensor nodes and also huge volume of multimedia data traffic cannot be handled by a single sink. Multi hop communication consumes more energy if the nodes are far away from the sink Multiple sink approach is used as a best solution found in the literature to solve these problems. In a multi-sink application scenario, simultaneous queries may generate traffic exceeding the transmission capacity of certain sensor nodes. To share the capacity of the sensors among multiple sinks by adjusting their query ranges, so that no sensor gets congested and every sink is able to monitor an area with desired data rate is presented in [16]. The mathematical model presented in [17] determines the locations of the sinks minimizing the sensors average distance from the nearest sink. The authors in [18], focused on the problem of placing multiple sinks such that the maximum worst-case delay is minimized while keeping the energy consumption as low as possible using a Genetic Algorithm paradigm. A scalable multi-path routing approach called Neighbor Sink Nexus routing algorithm is presented in [19] to find shortest possible route with maximum path aggregation but not at the cost of delay. In [20], a multi-sink WSN architecture is proposed where the network is partitioned into clusters. All the sources in a cluster are assigned to send data to the sink designated to that particular cluster.

2.3 Service Differentiation

The prime purpose of WSN is to disseminate various kinds of information about the environment they sense [1]. It is observed that information provided by the sensor nodes may have different levels of importance and the sensor networks should be willing to spend more resources in disseminating packets carrying more important information. In [21] authors introduced the concept of service differentiation as applicable to sensor networks, highlight its fundamental differences with normal data networks and define the relevant metrics. Traffic in WMSNs can be burst with a mixture of real-time and non-real-time traffic and most flows need real-time service which is bandwidth expensive. Bandwidth is a kind of rare resource in WMSN which is as important as, if not more important than energy resource [2] [3]. Dedicating available bandwidth solely to QoS traffic will not be acceptable. A trade-off in image/video quality may be necessary to accommodate non-real-time traffic. Usually in the WMSN, short period high priority traffic coexists with periodic low priority traffics and may have different level of service requirement to be satisfied from the underlying network. So service differentiation is very important in sensor networks, especially in WMSNs. To provide service differentiation in WMSNs, it is necessary to assign a different priority to each traffic source. Service differentiation in wireless sensor networks is a new research area and there are only a few published papers in this field. An Energy and QoS aware routing in WSN [22] is proposed which uses the cluster heads as gateways. The cluster heads are assumed to know the location of the sensor nodes to schedule data delivery and route setup. After sensor nodes collect the data, the data is passed to the cluster-head where the data may be fused or aggregated before sending to the sink or user. It has been shown that the protocol runs efficiently with best-effort traffic using single-r mechanism and multi-r mechanism where ‘r’ is the service rate. A novel QoS-aware routing protocol is presented in [23] to support high data rate for WMSN. Being multi-channel multi-path the foundation, the routing decision is made according to the dynamic adjustment of the required bandwidth and path-length-based proportional delay differentiation for real-time data and compared the results with single-r and multi-r mechanisms presented in [22].

Energy-Efficient QoS Routing (EEQR), is proposed in this paper, considers multi sink architecture of [20] and to form the cluster and select CH node follows the simulated annealing technique used in [9],[12]. The EEQR protocol consists of two phases. In the first phase clusters are formed and CH nodes are selected for each cluster. Each CH node calculates the least cost link for each sensor node in their clusters and indicates it as best cost link using Dijkstra’s Least Delay Routing Algorithm (DLDRA) and data is transferred on the best cost path which meets the e2e (end to end) QoS requirement.

3. Sensor Network Architecture

The proposed protocol uses the Two-sink WSN architecture shown in Fig.1. In the architecture, 50 sensor nodes are uniformly distributed and randomly scattered over the 1000×1000 m2. We consider a clustered multi sink wireless sensor network which is composed of four clusters with four event nodes and two sinks deployed. Transmission range is set to 250 m. Simulated annealing algorithm is used to form clusters and each cluster has a Cluster Head (CH) that manages all the sensors in the cluster. We assume that sensor, CH and sink nodes are stationary. Sensor data may originate from various types of events such as imaging and video data. Hence, packet scheduling policy should consider different priorities for different type of data traffic. For example, time-critical packets may be assigned with high priority compared to non-time-critical packets to meet the deadlines. The class based queuing model [24] is adapted in each sensor node, where different queues for the two different types of traffic such as Constant Bit Rate (CBR) traffic and video traffic and are labeled accordingly. On each node, there is a Packet classifier that checks the type of the incoming packets and sends to appropriate queues, and a scheduler that schedules the packets according to the delay and bandwidth requirements as shown in Fig. 2. All the sources in a cluster were assigned to send the data to the designated sink. Each CH node forward data packets among the neighbor nodes with maximum residual energy and reach the designated sink node finally. Real time data are sent on best path to the nearest sink and the non real time data are sent to any of the sinks reducing the congestion effect. In this way load is balanced among the two sinks and saves the energy of sensor nodes

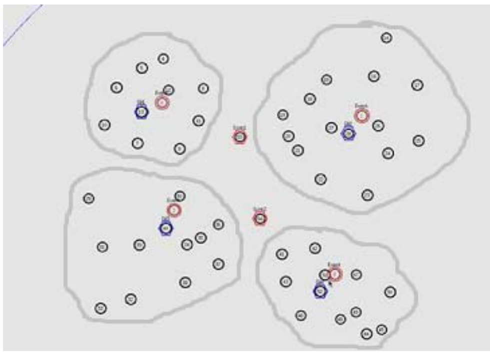
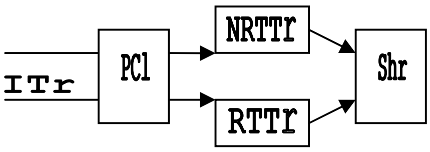


Fig. 1 System Architecture of MultSink Network



ITr-: Input Traffic, PCl: Packet classifier, Shr: Scheduler
NRTTr: Non Real Time Traffic, RTTr: Real Time Traffic

Fig. 2 Queing model at a sensor node

3.1 Assumptions

The basic assumptions of this scheme are:

- Each node is assigned a unique ID to help for identifying one node from other neighboring nodes.
- All the sensor nodes start with the same initial energy 8 joule before any traffic is routed through them.
- A two-ray ground radio propagation channel model is assumed with the channel capacity set to 2 Mbps.

3.2 Dijkstra's Least Delay Routing Algorithm (DLDRA)

Step1: Deleting any previous routing for the group and set source.
Step 2: locate source to get the peak rate.
Step 3: locate multicast group that contains the destination set.
Step 4: if (source is the first member in the tree) for (each node already in the tree) find the routing table entry for the given group and source.
Step 5: From source scan the adjacent list for the least cost link.
Step 6: if (the cost of the adjacent node i is less than the best cost so far && node i not already in the tree)
    Update the best cost
else
    Repeat the step 5 until all the node are scanned
Step 7: add the least cost node to the tree
Step 8: updates the links cost and add each link cost to the routing table of the best connection node.

3.3 EEQR Algorithm

Step 1. Setup Phase: Cluster Head selection and cluster formation
Step 2. Data Transmission Phase
Step 2.1 for (each sensor node i in the cluster)
Step 2.2. Calculate the least cost link using Dijkstra's Least Delay Routing Algorithm
Step 2.3 Update the best least cost path to the nearest sink From CH
Step 2.4 at sink check if e2e QoS can be met
Step 2.5 for (each path per destination)
    Calculate e2e = e2e(QD +PD)
    if (e2e >= e2e deadline)
    Connection is rejected to sink
    else
    Connection is allowed to nearest sink end for

In the proposed EEQR protocol, multiple events are assumed to be tracked. The nodes sensing the events will check the data generated is the conventional or the real time multimedia data. To find least cost path to the nearest sink, each CH node begins calculating the least cost link for each sensor node in their clusters and indicates it as best cost link using Dijkstra's Least Delay Routing Algorithm. Link costs are proportional to the peak rates of the traffic crossing these links. Each node locally checks delay requirement from sensor nodes to CH node and CH node to multiple sinks to ensure required delay. It calculates end-to-end (e2e) delay for each path considering Queuing Delay (QD) and propagation delay (PD). The real time data packets those exceeding the deadlines on a path are of no use and hence are to be dropped. So, that path can be rejected for further data transmission as it is not meeting the required e2e QoS. Otherwise connection is established for the best cost route to the nearest sink. For multimedia traffic the protocol chooses best path to the nearest sink based on link cost calculated in terms of residual energy and minimum number of hops towards the sink to minimize the packet loss and delay. This reduces the burden on single sink by balancing the load among the sinks and hence saves energy increasing the network lifetime. Our claims are well supported by simulation results

3.4 Flowchart

The flow chart depicted in Fig. 3 shows the flow of data from sensor node to the CH and then to the nearest sink based on type of the real-time and non real time data.

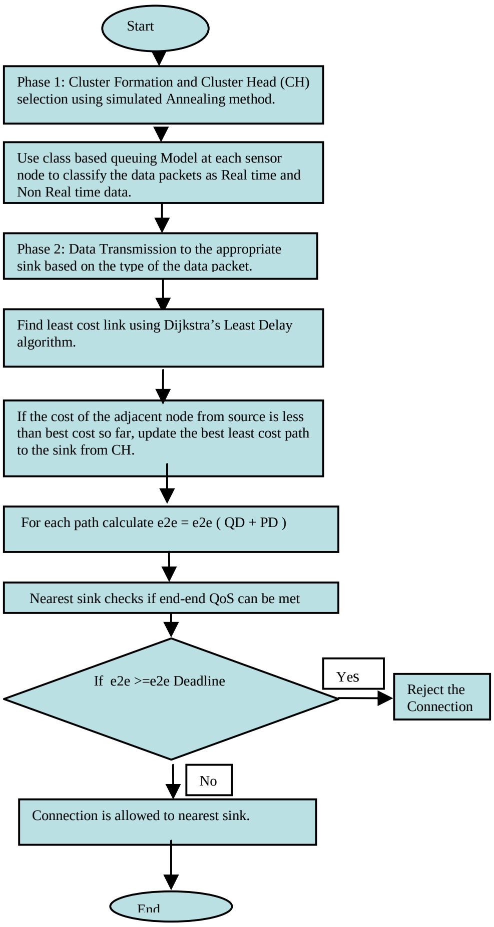


Fig. 3 Flowchart of the Proposed protocol

4. Performance Evaluation

The effectiveness of the proposed QoS-aware routing approach is evaluated through simulation in ns-2 [25]. We consider the packet drop, delivery ratio and end to end delay as three important performance evaluation parameters. The traffic rate is set to 500kbps with the packet size as 500bytes. The effect of varying the buffer size on performance is evaluated by repeating the simulation process for several times

4.1 Simulation Parameters

The Table I shows the parameters that are considered for use in the simulation

Table 1: Simulation Parameters

Parameter Name	Value
Channel Type	Channel/WirelessChannel
Radio-Propagation model	Propagation/TwoRayGround
Network interface type	Phy/WirelessPhy
Mac Type	Mac/802_11
Interface Queue Type	Queue/DropTail/PriQueue
Link Layer Type	LL
Antenna model	Antenna/OmniAntenna
Grid Size	1000 X 1000 m^2
Initial Energy	8 joules
Nodes Status	Static
Nodes Number	50

4.2 Performance Metrics

The obtained results for the proposed two sink model with CBEEQR scheme is compared with single sink architecture. The definitions of the parameters considered are as follows:

- *Packet Dropping Rate*: It shows the number of data packets which were dropped during their journey to reach the sink.
- *Packet Delivery Ratio*: It shows the ratio of total packet received at sinks, to the total packets which are sent by source nodes.

Average delay per packet: It is defined as the average time a packet takes from source to the sink

4.3 Simulation Results

In this section, we analyze the effect of multi-sinks on the performance of the wireless multimedia sensor network. We are interested in the network lifetime and overall energy consumption. The queuing model employed uses buffers in each node and there is a limit on the size of those buffers. We varied the buffer size to see if this has any effect on the performance of the algorithm.

From the Fig. 4, it is clear that as the size of buffer increases the packet drop becomes less in two sink model compared to single sink. The packet drop decreases with increase in buffer size since number of packets arriving to the nearest sink is more.

Packets are not dropped when there is enough space in the buffers. The packets from far nodes will also be able to reach within deadline because of packet forwarding to the nearest sink. Due to less packet loss most of the packets reach the destination which increases the delivery ratio in the two sink model compared to single sink model as depicted in Fig. 5.

We varied the buffer size and monitored how this change affects the end-to-end delay. It is shown in Fig. 6 that average delay per packet increases with increase in buffer size. The delay is more in single sink compared to two sink model as most of packets directed to the nearest sink balancing the traffic in case of two sink model.

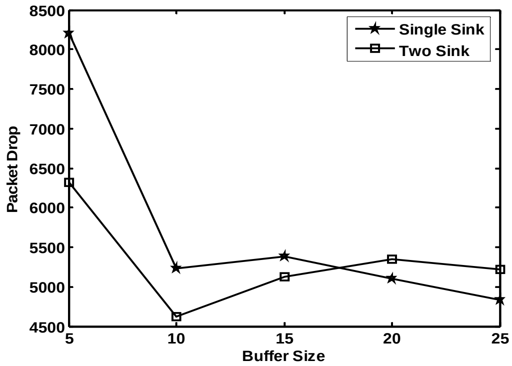


Fig. 4. Packet Drop

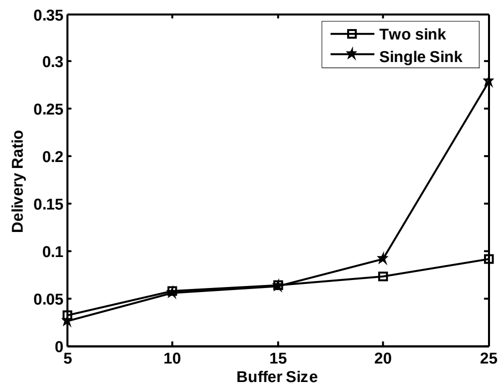


Fig. 5 Delivery Ratio

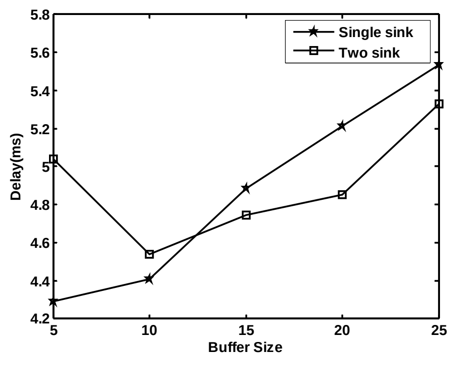


Fig. 6 End to End Delay

5. Conclusion

The deployment of multi-sink wireless sensor networks got advantages in terms of network lifetime and event reporting reliability and are analyzed under the assumption that events are generated randomly. Simulation results show that multi-sinks network deployment provides better performance with respect to single sink model. This paper analyzes the delay and energy problem in routing based on clustered and multi sink WMSN attributes.

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