QoS-Aware Routing for Sensor Networks Using Distance-Based Proportional Delay Differentiation (DPDD)

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***Abstract*-Many routing protocols have been proposed for wireless sensor networks. The majority of these protocols considered energy efficiency as the main objective and assumed data traffic with unconstrained delivery requirements. But the introduction of image and video sensors demand certain quality of services (QoS) from the routing protocols and underlying networks. Managing such real-time data requires both energy efficiency and QoS assurances in order to ensure efficient usage of sensor resources and correctness of the collected information. In this paper we propose a routing protocol that will ensure end-to-end delay requirement of collected real-time data. At the same time the throughput of non-real-time data is maximized by adjusting the service rate of real-time and non-real-time data.**

I. INTRODUCTION

Recent advances in ultra-high integration and low-power design have led to active research in large-scale, highly distributed systems of small-size, wireless unattended sensors. In addition to the sensing circuitry, a sensor typically includes a signal-processor and a radio. The sensing circuitry measures ambient conditions, related to the environment surrounding the sensor and transforms them into an electric signal. The sensor sends such collected data via the radio transmitter. The continuous decrease in the size and cost of sensors has motivated intensive research addressing the potential of collaboration among sensors in data gathering and processing via an ad hoc wireless network.

Routing of sensor data has been one of the challenging areas in wireless sensor network research [1, 2]. Current research on routing of sensor data mostly focused on protocols that are energy aware to maximize the lifetime of the network, scalable for large number of sensor nodes and tolerant to sensor damage and battery exhaustion.

Since such energy consideration has dominated most of the research in sensor networks, the concepts of latency, throughput and delay jitter were not primary concerns in most of the published work on sensor networks. However, the increasing interest in real-time applications along with the introduction of imaging and video sensors has posed additional challenges. For instance, the transmission of imaging and video data requires careful handling in order to ensure that end-to-end delay is within acceptable range and the variation in such delay is acceptable. Such performance metrics are usually referred to as quality of service (QoS) of the communication network. Therefore, collecting sensed imaging and video data requires both energy and QoS aware network protocols in order to ensure efficient usage of the sensors and effective access to the gathered measurements.

QoS protocols in sensor networks have several applications including real-time target tracking in battle environments, emergent event triggering in monitoring applications etc. In a battle environment in order to identify a target, to identify the movements of the targets we need either image of the target or video. In such an environment we should employ imaging or video sensors. After detecting and locating a target using contemporary types of sensors, e.g. acoustic, imaging sensors can be turned on to capture a picture of such a target periodically for sending to the controller. Since, it is a battle environment; this requires a real-time data exchange between sensors and controller in order to take the proper actions. Delivering such time-constrained data requires certain bandwidth with minimum possible delay and thus a service differentiation mechanism will be needed in order to guarantee timeliness.

This paper is organized as follows. Section 2 describes related works. Section 3 gives motivation for our QoS-aware routing protocol. In section 4 we explain an example network model where QoS-aware routing will be applied. Section 5 details our proposed method of incorporating QoS into a multi-hop sensor network routing protocol. Section 6 presents the simulation and results. We conclude in section 6 by conclusion and future works.

II. RELATED WORK

While incorporating QoS for data routing in wireless networks (e.g., ad hoc networks) is not uncommon, very little attention has been paid to QoS constrained traffic in wireless sensor networks. Recently few research projects have started to emerge addressing the support of QoS requirements in wireless sensor networks. The first category focuses on the energy and delay trade-off without much consideration to the other issues. The second category strives to spread traffic in

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This work was supported by ITRC Project of MIC

order to effectively boost the bandwidths and decrease the delay.

A fairly new QoS aware protocol for sensor networks is proposed by Akkaya and Younis [3]. Real-time traffic is generated by imaging sensors and delivered to the controller through the gateway by using multi-hop routing. The proposed protocol extends the routing approach in [12] and finds a least cost and energy efficient path that meets certain end-to-end delay during the connection. The link cost used is a function that captures the nodes' residual energy, transmission energy, error rate and other communication parameters.

In order to support both best effort and real-time traffic at the same time, a class-based queuing model is employed. The queuing model allows service sharing for real-time and non-real-time traffic. The bandwidth ratio *r*, is defined as an initial value set by the gateway and represents the amount of bandwidth to be dedicated both to the real-time and non-real-time traffic on a particular outgoing link in case of a congestion. As a consequence, the throughput for normal data does not diminish by properly adjusting such "*r*" value. The queuing model is depicted in Fig. 1, which is drawn from [3]. The protocol finds a list of least cost paths by using an extended version of Dijkstra's algorithm and picks a path from that list which meets the end-to-end delay requirement.

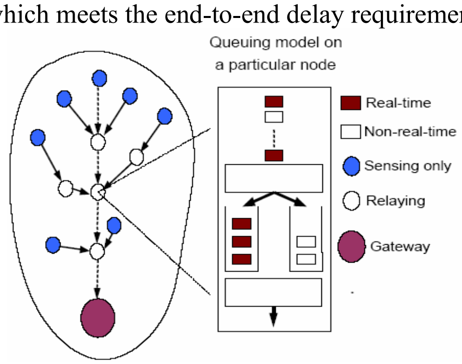

Fig. 1: Queuing model in a particular sensor node

They showed by simulation that the proposed protocol consistently performs well with respect to QoS and energy metrics. However, the same r-value is set initially for all nodes, the selection is done in such a way so that it will satisfy the least hop node's delay requirement, which does not provide flexible adjusting of bandwidth sharing for different links. Also the average delay increases with higher real-time data rate which becomes very worse with a rate of real-time data 10 packet/sec.

The protocol is extended in [4] by assigning a different r-value for each node in order to achieve a better utilization of the links. Also, the average delay per packet does not increase too much with the increase of real-time data rate. But finding the r values and sending these to the particular node is not only an overhead but energy consuming as well, since the r values have to be unicasted to every single node. Moreover, when a route changes a set of new r values for all the nodes in the new route have to be calculated and transmitted to the nodes.

III. MOTIVATION

Several energy-aware multi-hop routing protocols have been proposed for wireless sensor networks without considering QoS. These routing protocols divides the network into number of clusters and the cluster-heads relay the data to a particular cluster-head that will finally transmit the data to the base station. If imaging sensors are used data rate will be increased. Therefore when congestion occurs, data will be queued in the forwarding nodes and these routing protocols will not consider the end-to-end delay of real-time data.

We will propose a QoS-aware routing protocol which is built off multi-hop energy-aware routing protocol. We assume that all nodes including the cluster-heads know its distance in hop count from the gateway. We also assume that the real-time data generation by every imaging sensor is same. Therefore, forwarding nodes closer the gateway will have more real-time data than a distant one, and need more bandwidth for the real-time data. Like [4] multi-valued *r* will be used to determine the bandwidth used by real-time and non-real-time traffic. The gateway will broadcast a single *r* value to all the nodes and the nodes will recalculate its own r value based on the distance of the nodes from the gateway. Also the forwarding nodes will use queues with different service classes for the real-time data.

IV. NETWORK MODEL

The network model is based on the model developed by Akkaya et al. in [4]. It consists of a set of sensors spread throughout an area of interest to detect and possibly track events/targets in this area. The sensors are battery-operated with limited data processing engines. Some of the sensors (or all the sensors) are imaging sensors and equally distributed throughout the network area. The sensors can dynamically change to serve the need of one or multiple command nodes. Command nodes can be stationary or mobile. In a disaster management environment, coordination centers are typical stationary command nodes, while paramedics, fire trucks, rescue vehicles and evacuation helicopters are examples of mobile command nodes. A gateway node is a less energy-constrained node deployed in the physical proximity of sensors. The gateway is responsible for organizing the activities at sensor nodes to achieve a mission, fusing data collected by sensor nodes, coordinating communication among sensor nodes and interacting with command nodes. We are considering both the gateway and sensor nodes as stationary. All the sensors are assumed to be within the communication range of the gateway node. The architecture is depicted in Fig 1 and taken from [4].

The sensor is assumed to be capable of operating in an active mode or a low-power stand-by mode. The sensing and processing circuits can be powered on and off. In addition both the radio transmitter and receiver can be independently turned on and off and the transmission power can be programmed for a required range. It is also assumed that the sensor can act as a relay to forward data from another sensor. It is worth noting that most of these capabilities are available on some of the advanced sensors, e.g. the Acoustic Ballistic Module from SenTech Inc. [5]. The gateway node is assumed to know its location, e.g. via the use of GPS and all nodes know their distance from gateway.

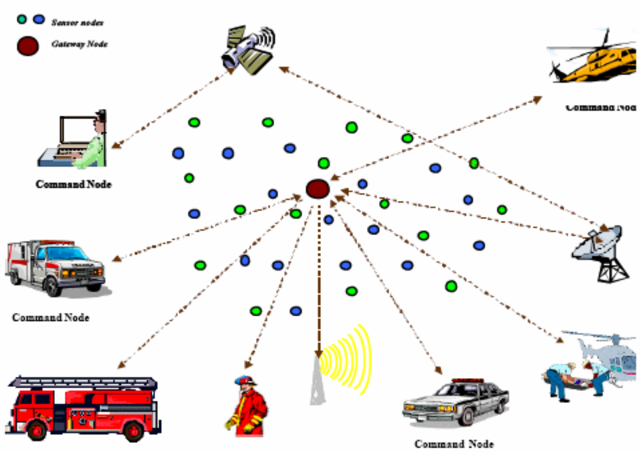

Fig. 2: Example Sensor Network Architecture

V. QoS-AWARE ROUTING PROTOCOL

A. Overview

We propose a QoS-aware routing protocol with the following key characteristics:

1. A multi-hop routing protocol is used as the base routing protocol and our QoS assurance mechanism will work with this.
2. A parameter *r* will be used that determines the bandwidth used by the real-time and non-real-time data. The gateway will determine the value of r based on the observed delay of real-time data and will broadcast the value to all the cluster-heads. After receiving the value all the cluster-heads will calculate their own value of r based on the distance of the nodes from the gateway.
3. Our proposed scheme will use N ordered queues for the real-time data. A Distance-based Proportional Delay Differentiation (DPDD) model will determine the delay encounter by each packet in a particular queue.
4. Finally, waiting time priority algorithm [6] will be adopted so that packet will be de-queued from the queues according to the service class and waiting time.

B. Multi-hop Routing

We use a multi-hop routing protocol as the base routing protocol that finds the shortest path from the source to the gateway which is energy efficient. The networking area is divided into number of clusters and nodes in the cluster are selected as cluster head by turn. All the nodes within the cluster transmit data to the cluster head. The cluster heads of different clusters form either a chain or tree so that data can be forwarded to the gateway in a multi-hop basis. Also we assume that all nodes know the distance (hop count) to the gateway.

Several cluster based multi-hop routing protocols for sensor networks have been proposed, namely PEGASIS [7], Hierarchical-PEGASIS [8], TEEN [9], APTEEN [10]. Our proposed QoS mechanism will work with any of these routing protocols with minimal or no modifications.

C. QoS Assurance

QoS is an agreement to provide guaranteed services, such as bandwidth, delay, delay jitter and packet delivery rate to users. We only consider the end-to-end delay constraint when studying QoS-aware routing for supporting real-time data. In the example network, both real-time and non-real-time traffic coexist. We not only should find paths that meet the QoS requirements for real-time traffic, but need to maximize the throughput for non-real-time traffic as well. Therefore it is important to prevent the real-time traffic from consuming the bulk of network bandwidth and leave non-real-time data starving and thus incurring large amount of delay. To maximize the non-real-time traffic we will ensure that real-time traffic will experience maximum allowed end-to-end delay.

We assume that propagation delay is very negligible and delay incurred by a packet is due to the queuing delay at every node. Therefore, the end-to-end delay is the sum of all queuing delays in a path. As packets travel using the shortest path, delay of a packet can be reduced by decreasing the queuing delay. Also we assume that the cluster heads can aggregate the non-real-time data to reduce the number non-real-time packets.

C.1. DPDD Service Model

The Distance-based Proportional Delay Differentiation (DPDD) is a DiffServ-based service which is an extension of PDD [11] defined for wired network. The DPDD service model supports N classes relatively ordered in per-hop packet queuing delays at any node. At node *k*, packets from class *i* experience smaller delay than class *j* for all $i > j$, $i, j \in S_{B,k}$, where $S_{B,k}$ is the set of backlogged classes at node *k*. The spacing between delays is tuned by the gateway based on observed delay of the real-time packet with a set of class differentiation parameters. As its name suggests, the model not only holds at each node, it also holds across all nodes in a path. The DPDD service model is defined as follows. Let $1 = \delta 1 > \delta_2 > \ldots. > \delta_N > 0$ be delay differentiation parameters (DDPs) and $\overline{d}_i^{(k)}$ denote the average queuing delay of class *i* packets at node *k*. The DPDD requirement is

$$\frac{\overline{d}_i^{(k)}}{\overline{d}_j^{(q)}} = \frac{\delta_1}{\delta_2}$$

for all classes *i* and *j* and between all pairs of nodes those belong to the same path.

Fig. 3 shows the DPDD-based service assurance framework. Real-time delay sensitive packets go through Dynamic Class Selection (DCS) algorithm. DCS select the service class of the packets based on the distance of the node from the gateway.

No intermediate node can change the service class of the packets.

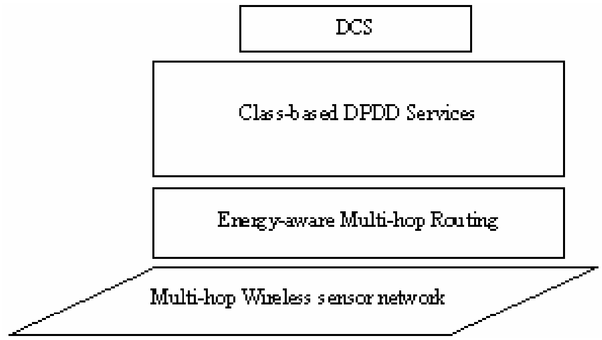

Fig 3: DPDD-based service assurance framework

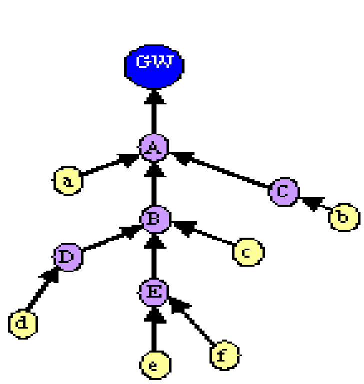

Fig 4: Dynamic class Selection (DCS) of packets

Fig. 4 shows how DCS selects the service class. Nodes A, B, C, D and E are forwarding nodes and a, b, c, d, e and f are regular nodes. As seen from the figure node A experiences more congestion than node B and node B experiences more congestion than any of the nodes C, D and F. Also packets from nodes d, e and f have to travel more nodes than packets from nodes a, b and c. DCS selects the service class so that packets those travel longer distance will have higher service class and have lower delay in every forwarding node. So if the maximum hop count from gateway is N then exactly N classes are required. (Number of service class can be reduced by putting packets of closer hop count in one class, say packets of hop count 6 and 5 in one service class and 4 and 3 in another.) For example, packets from node e have to travel 4 hops and so placed in the service class 4. Now we define the average total queuing delay $\hat{d}_i$ where packets will travel exactly i hops and in service class i. If DPDD holds, the DDPs are made in such a way so that all packets have the same average total queuing delay. That is

$$\hat{d}_i = \hat{d}_j \qquad \forall i, j \in \{1 \ldots N\}$$

for any two nodes having hop count i and j in the same path.

C.2. Adaptive Bandwidth Sharing

As both real-time and non-real-time traffic co-exist, bandwidth should be used effectively so that not only the QoS requirements of real-time traffic are met but service to the non-real-time traffic is maximized as well. As mentioned earlier a parameter r is used to control the bandwidth used by real-time and non-real-time traffic. As shown in Fig. 4 node A has more real-time traffic than node B and accordingly should allocate more bandwidth and a multi-valued r is required. We assume that the rate of real-time data is almost inversely proportional to the hop count of the node from the gateway. The gateway will select a value of r in between 1.5 and 2 (or can be selected by the network designer) based on the observed delay. Every cluster head calculates its own r-value by using the following formula:

$$r_i = \frac{r}{i + x}$$

where *i* is hop count of the node from the gateway, x is the adjusting factor having value between 1 and 2 and the node will set the value based on the incoming traffic. The value of x determines the maximum bandwidth utilized be the real-time traffic at any node. When the gateway observes that the end-to-end delay is increased it increased the value of r to allocate more bandwidth to real-time traffic and vice versa. Also the gateway tries to make the value of r as minimum as possible without violating the QoS requirement to maximize the bandwidth use of non-real-time traffic. Finally, Fig. 5 shows he implemented mechanism at each node.

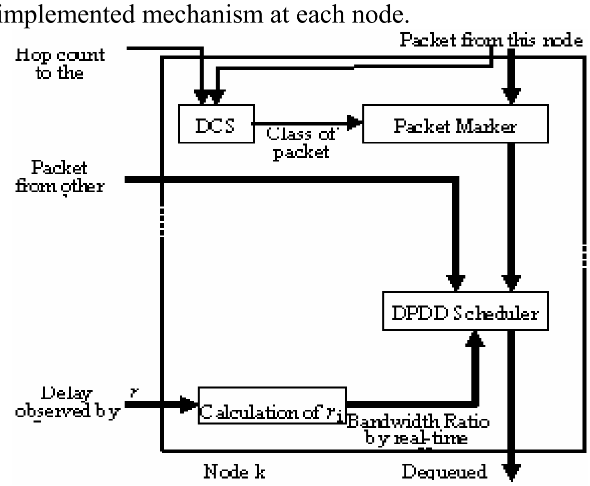

Fig. 5: End-to-end QoS assurance mechanisms based on DPDD and DCS

C.3. DPDD Scheduler

The DPDD scheduler services packets in classes and realizes proportional average per-hop delays among them locally at each node. The waiting time priority (WTP) algorithm [11] is adopted for the scheduler. With WTP, each class is serviced with a separate first-in–first-out (FIFO) queue. The head-of-line packet of a class is assigned a WTP based on the service class and waiting time of the packet and the scheduler always schedules the highest priority head-of-line packet for transmission.

VI. SIMULATION

In this section, we present some performance results obtained by simulation. Performance metrics that we considered are average life time of a node, average delay per packet and network throughput. Parameters those affect the metrics are buffer size, packet drop probability and real time data generation rates. We compare the performance of our proposed protocol with the single-r and multi-r mechanism of [4].

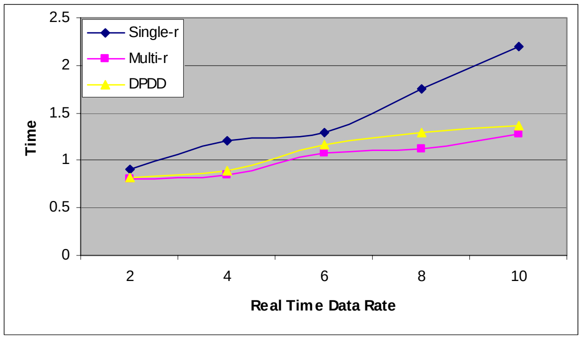

Fig. 6: Average delay per packet with different real-time data rates.

Fig. 6 shows comparison of average packet delay generated and our proposed model and single-r and multi-r mechanism. Our model has less delay as compared to single-r mechanism but experiences a bit more delay than the multi-r mechanism.

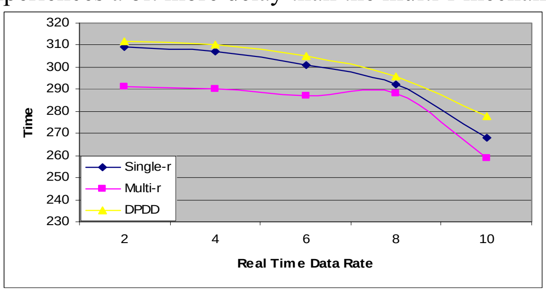

Fig. 7: Average lifetime of a node with different real-time data rates.

Fig. 7 shows the average lifetimes of the nodes and it is found that our model consumes less energy as compared to both the models. The reason is that it does not require multiple unicast transmission of the r value like multi-r mechanism. The base energy-aware routing protocol does some aggregation of non-real-time data to reduce energy consumption. Also as the cluster heads are changed randomly, the time to die the first node will also increased.

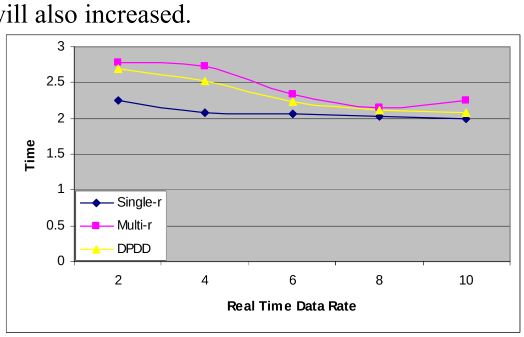

Fig. 8: Non-real-time data throughput for different real-time data rates.

Fig. 8 shows the throughput of non-real-time data with different real-time data rates. Even though the value is less than multi-r but it requires less energy consumption and computation as compared to the multi-r mechanism.

VII. CONCLUSION AND FUTURE WORK

In this paper, a new QoS aware routing protocol has been presented for wireless sensor networks. This protocol ensures the end-to-end delay requirements of the real-time image data. A DPDD based service model is proposed that provides proportional delay at every node based on the distance of the source from the gateway. A parameter r is defined which adjust the bandwidth usage of real-time data with changing traffic rate. Both DPDD and the value of r ensure the end-to-end delay requirements. At the same time, the throughput of non-real-time data is maximized.

No data aggregation has been considered for the image data. We like to extend our work by considering real-time data aggregation both at the source node and forwarding nodes. This data aggregation will increase both the energy efficiency and bandwidth usage of sensor networks.

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