Multi-path and Multi-source QOS Control Algorithm for Maximizing the System Lifetime of Query-Based WSN

S T Pir jade¹ Vinod kumar Kumar Bhutnal² Ramachandra H V³

*Asst. Professor, Department of Computer Engineering, Rajarshi Shahu College of Engineering, Tathawade, Pune-33, India.
**Asst. Professor, Department of Computer Engineering, Rajarshi Shahu College of Engineering, Tathawade, Pune-33, India.
***Asst. Professor, Department of Computer Engineering, Rajarshi Shahu College of Engineering, Tathawade, Pune-33, India.

Abstract: In this paper, we develop multi-path and multi-source quality of service (QoS) control algorithms based on hop-by-hop data delivery utilizing “source” and “path” redundancy, with the goal to satisfy application QoS requirements while prolonging the lifetime of the sensor system. We discover that there exists optimal “source” and “path” redundancy under which the lifetime of the system maximized while satisfying application QoS requirements.

Index Terms: Wireless sensor networks, reliability, timeliness, query processing, redundancy, energy conservation, QoS mean time to failure.

I. Introduction

A WSN can be either source-driven or query-based depending on the data flow. In source-driven WSNs sensors initiate data transmission for observed events to interested users, including possibly reporting sensor readings periodically. An important research issue in source driven WSNs is to satisfy QoS requirements of event-to-sink data transport while conserving energy of WSNs. In query based WSNs, queries and data are forwarded to interested entities only. In query-based WSNs, a user would issue a query with QoS requirements in terms of reliability and timeliness.

Retrieving sensor data such that QoS requirements are satisfied is a challenging problem and has not been studied until recently [3], [4], [5], [6], [7], [8]. The general approach is to apply redundancy to satisfy the QoS requirement. In this paper, we are also interested in applying redundancy to satisfy application specified reliability and timeliness requirements for query-based WSNs. Moreover, we aim to determine the optimal redundancy level that could satisfy QoS requirements while prolonging the lifetime of the WSN. Specifically, we develop the notion of “path” and “source” level redundancy. When given QoS requirements of a query, we identify optimal path and source redundancy such that not only QoS requirements are satisfied, but also the lifetime of the system is maximized. We develop multi-path and multi-source QoS control (MMQC) algorithms based on hop-by-hop data delivery to achieve the desired level of redundancy and to eliminate energy expended for maintaining routing paths in the WSN.

The rest of the paper is organized as follows: In Section 2, we survey related work. In Section 3, we discuss the WSN system model. In Section 4, we develop proposed model for computing the lifetime of a query-based WSN as a function of “path” and “source” redundancy being employed, defined as the number of queries that the system is able to execute successfully in terms of QoS satisfaction before failure. We also discuss extension to the data aggregation. Finally, Section 5 concludes the paper and discusses future work.

II. Related Work

Existing research efforts related to applying redundancy to satisfy QoS requirements in query-based WSNs fall into three categories: traditional end-to-end QoS, reliability assurance, and application-specific QoS [3]. Traditional end-to-end QoS solutions are based on the concept of end-to-end QoS requirements. The problem is that it may not be feasible to implement end-to-end QoS in WSNs due to the complexity and high cost of the protocols for resource-constrained sensors. An example is Sequential Assignment Routing (SAR) [4] that utilizes path redundancy from a source node to the sink node. Each sensor uses a SAR algorithm for path selection. It takes into account the energy and QoS factors on each path, and the priority level of a packet. For each packet routed through the network, a weighted QoS metric is computed as the product of the additive QoS metric and a weight coefficient associated with the priority level of that packet. The objective of the SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network. The
algorithm does not consider the reliability issue. ESRT [9] has been proposed to address this issue with reliability as the QoS metric. ReInForM has been proposed [5] to address send-to-end reliability issues. ReInForm considers information awareness and adaptability to channel errors along with a differentiated allocation strategy of network resources based on the criticality of data. The protocol sends multiple copies of a packet along multiple paths from the source to the sink such that data is delivered with the desired reliability. It uses the concept of dynamic packet state to control the number of paths required for the desired reliability using local knowledge of the channel error rate and topology. The protocol observes that for uniform unit disk graphs, the number of edge-disjoint paths between nodes is equal to the average node degree with a very high probability. This protocol results in the use of the disjoint paths existing in a thin band between the source and the sink. However, the protocol only concerns QoS in terms of reliability.

In [6], M. Perillo and Heizelman provide application QoS with the goal of maximizing the lifetime of WSNs while satisfying a minimum level of reliability. This maximization is achieved through the joint optimization of scheduling active sensor sets and finding paths for data routing. The lifetime is defined as the sum of the time that all sensor sets are used. The approach uses the strategy of turning off redundant sensors for periods of time to save energy while considering the trade-off between energy consumption and reliability. This approach can extend the lifetime of a network considerably compared with approaches that do not use intelligent scheduling. However, this approach is not scalable and QoS is limited to application reliability only. Recently, a multipath and multispeed routing protocol called MMSPED is proposed in [7] which takes into account both timeliness and reliability as QoS requirements. The goal is to provide QoS support that allows packets to choose the most proper combination of service options depending on their timeliness and reliability requirements. For timeliness, multiple QoS levels are supported by providing multiple delivery speed options. For reliability, multiple reliability requirements are supported by probabilistic multipath forwarding. The protocol provides end-to-end QoS provisioning by employing localized geographic forwarding using immediate neighbor information without end-to-end path discovery and maintenance. It utilizes dynamic compensation which compensates for inaccuracy of local decision as a packet travels toward its destination. The protocol adapts to network dynamics. However, MMSPED does not consider energy issues. Our work considers energy consumption, in addition to reliability and timeliness requirements as in MMSPED. Further, we also consider network dynamics due to sensor failures, energy depletion, and sensor connectivity. Utilizing hop-by-hop delivery, the MMQC algorithm developed in our work specifically forms multipath redundancy paths for path redundancy and ms sensors for source redundancy to satisfy the imposed QoS requirements, facilitating the determination of the best(mp, ms) that would maximize the lifetime of the WSN.

In [8], QoS is defined as the optimum number of sensors that should be sending information to the sink at any given time. The protocol utilizes the base station to communicate QoS information to each of the sensors using a broadcast channel. It exploits the mathematical paradigm of the Gur Game to dynamically adjust to the optimum number of sensors. The objective is to maximize the lifetime of the sensor network by having sensors periodically powered down to conserve energy, and at the same time, having enough sensors powered up and sending packets to the sink to collect enough data. The protocol allows the base station to dynamically adjust the QoS resolution. This solution requires the determination of the amount of sensors that should be powered up a priori to maintain a solution. QoS metrics for data delivery such as reliability and timelines are not considered. Clustering SN prolongs the system lifetime of a WSN [1], [2] because clustering reduces contention on wireless channels [10] and supports data aggregation and forwarding at cluster heads (CHs). HEED [1] increases energy efficiency by periodically rotating the role of CHs among SNs with equal probability such that the SN with the highest residual energy and node proximity to its neighbors within a cluster area is selected as a CH. In LEACH [2], the key idea is to reduce the number of nodes communicating directly with the base station by forming as small number of clusters in a self-organizing manner. LEACH uses randomization with equal probability in cluster head selection to achieve energy balance. REED [11] considers the use of redundancy to cope with failures of SNs in hostile environments. We also consider cluster-based WSNs for energy reasons. Our approach of satisfying application reliability and timeliness requirements while maximizing the system lifetime is to determine the optimal level of redundancy at the “source” and “path” levels. The source-level redundancy refers to the use of multiple sensors to return the requested sensor reading. The path-level redundancy refers to the use of multiple paths to relay the reading to the sink node. Since WSNs are constrained with resources, the MMQC algorithm developed in this paper utilizes hop-by-hop data delivery and dynamically forms multiple paths for data delivery, without incurring extra overhead to first formulate multiple paths before data delivery. Our contribution is that we identify the best level
of redundancy to be used to answer queries to satisfy their QoS requirements while prolonging the lifetime of query-based WSNs.

III. System Model

A WSN consists of a set of low-power sensor nodes (SNs) typically deployed through air-drop into a geographical area. SNs are homogeneous and indistinguishable with the same initial energy level. A clustering algorithm (e.g., [1], [2]) that aims to fairly rotate SNs to take the role of CH has been used to organize sensors into clusters for energy conservation purposes, as illustrated in Fig. 1. A CH is elected in each cluster. The function of a CH is to manage the network within the cluster, gather sensor reading data from the SNs within the cluster and relay data in response to a query. The clustering algorithm is executed periodically by all SNs. Routing in the WSN is based on geographic forwarding (e.g., [6]). No path information needs to be maintained by individual SNs to conserve energy. Essentially, only the location information of the destination SN needs to be known by a forwarding SN for any source-destination communication. We note that when a CH is elected periodically, the location information is broadcast to the WSN to let other CHs know its location. Also, SNs within a cluster know the location of their CH, and vice versa, as part of the election process. A source CH must relay sensor data information to the PC in response to a user query, and thus, can consume more energy than an SN within its cluster. The energy consumed by the system for forwarding data in response to a query depends on the total length (in terms of the number of hops) of the paths connecting m SNs within a cluster to the source CH for source redundancy, and the total length of the m paths connecting the source CH and the processing center (the destination CH) for path redundancy. To save energy, SNs operate in power saving mode. At this mode, an SN operates either in active mode, i.e., transmitting or receiving, or in sleep mode.

IV. Proposed Model

The multi-path and multi-source QoS control (MMQC) algorithm developed in this paper takes two forms of redundancy. The first form is path redundancy. That is, instead of using a single path to connect an active node to the processing center, multiple disjoint paths may be used. The second is source redundancy. That is, instead of having one sensor node in a source cluster retrieving requested sensor data, m sensor nodes may be used to return readings to data transmission to the PC in response to a user query, and thus, can consume more energy than an SN within its cluster. The energy consumed by the system for forward data forwarding in response to a query depends on the total length (in terms of the number of hops) of the paths connecting m SNs within a cluster to the source CH for source redundancy, and the total length of the m paths connecting the source CH and the processing center (the destination CH) for path redundancy. To save energy, SNs operate in power saving mode. At this mode, an SN operates either in active mode, i.e., transmitting or receiving, or in sleep mode.

4.1 Data Aggregation

The analysis performed thus far assumes that a source CH does not aggregate data. The CH may receive up to m redundant sensor readings due to source redundancy but will just forward the first one received to the PC.
Thus, the data packet size is the same. For more sophisticated scenarios, conceivably the CH could also aggregate data for query processing and the size of the aggregate packet may be larger than the average datapacket size. We extend the analysis to deal with data aggregation in two ways. The first is to set a larger size for the aggregated packet that would be transmitted from a source CH to the PC. This will have the effect of favoring the use of a smaller number of redundant paths (i.e., mp) because more energy would be expended to transmit aggregate packets from the source CH to the PC. The second is for the CH to collect a majority of sensor readings from its sensors before data are aggregated and transmitted to the PC.

V. Conclusion And Future Work

In this paper, we have developed an multipath and multi-source QoS control (MMQC) algorithm which incorporates path and source redundancy mechanisms to satisfy query QoS requirements while maximizing the lifetime of query-based sensor networks. We discussed how these mechanisms can be realized using hop-by-hop packet delivery and amount of energy consumed per query. When given a set of parameter values characterizing the operating and workload conditions of the environment, we identified the optimal (mp, ms) setting that would maximize the MTTF while satisfying the application QoS requirements.

In the future, we plan to provide a more detailed analysis of the effect of network dynamics on MTTF, such as more energy may be consumed by some SNs over others or some SNs may fail earlier than others. Finally, we plan to consider the use of acknowledgment and timeout mechanisms in our hop-by-hop data delivery scheme at various levels, such as hop-by-hop or end-to-end, and identify the optimal (mp, ms) that minimizes MTTF, as well as conditions under which no-ACK is better than ACK-based data delivery schemes, or vice versa.

References