Volume 3, Issue 1, January 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

The Quality of Service Support for Wireless Sensor Networks

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Abstract— To provide trustworthy and timely information is the most important tasks of wireless sensor networks. Providing quality of service (QoS) to satisy the end users and matching WSN constraints, has become an significant research work. Nevertheless, majority of research in this area has overlooked the fact that ensures the QoS requires a cross-layer approach straddling through all layers of the protocol stack. Transmission of data in this scenario requires both energy and QoS aware network management in order to ensure efficient usage of the sensor resources and effective access to the gathered measurements. In this paper we highlight the architectural and operational challenges of handling of QoS traffic in sensor networks and to increase the energy efficiencyof the sensors.

***Index Terms* - QoS, WSN, routing, energy**

I. INTRODUCTION

Recent technological development step forward particularly in high integration and low-power electronics which enabled the development of miniature battery-operated sensors [1-4]. In addition to the sensing circuitry, a sensor includes a signal-processor and a radio. The sensing circuitry measures the physical parameters surrounding the sensor and transforms them into an electric signal. Processing those signal divulges the properties of the objects located around the sensor and the events happening in the vicinity of the sensor. The sensor sends the collected data through the radio transmitter, to a command center (sink) either directly or through a data concentration center (a gateway). The gateway performs fusion of the sensed data in order to filter out the erroneous data and anomalies and to draw conclusions over a period of time. The frequent reduction in size and cost of sensors has motivated rigorous research addressing the potential of collaboration among sensors in gathering the data and processing it through wireless network. The unattended sensor nodes in the network are estimated to have noteworthy impact on the efficacy of many civil and military applications. In calamity scenarios such as earthquake, sensor networks can be used to selectively map the affected regions directing emergency response units to survivors. Sensors in such environments are energy constrained which cannot be recharged. Therefore, designing energy-aware algorithms become an important factor for extending the lifetime of sensor networks [5][6].

The signal processing and communication activities are the main consumers of sensor's energy. Since sensors are battery-operated, keeping the sensor active all the time will reduce the battery's lifetime. Therefore, optimal organization and management of the sensor network is crucial in order to perform the desired function with an acceptable level of quality and to maintain sufficient sensor energy for the required mission. Mission-oriented organization of the sensor network enables the appropriate selection of only a subset of the sensors to be turned on and thus avoids wasting the energy of sensors that do not have to be involved. Energy-aware network management will ensure a desired level of performance for the data transfer while extending the life of the network.

Energy constraints combined with a typical deployment of large number of sensor nodes have necessitated energy-awareness at most layers of networking protocol stack. Current research on routing in wireless sensor networks mostly focused on protocols that are energy aware to maximize the lifetime of the network, that are scalable to accommodate a large number of sensor nodes, and are tolerant to sensor damage due to battery exhaustion [7][8][9][10]. In addition, accessing the medium is a major consumer of sensor energy, especially when the radio receiver is turned on all time. Energy consumed for radio transmission is directly proportional to the distance squared and can significantly magnify in a noisy environment. Energy-aware routing can optimize the transmission energy, while collision avoidance and minimization of energy consumed by the receiver can be achieved via energy-efficient medium access control (MAC) mechanisms [11][12][13].

Energy-aware QoS routing in sensor networks will ensure guaranteed bandwidth through the duration of a connection as well as providing the use of the most energy efficient path. To the best of our knowledge, little attention has been paid by the research community to addressing QoS requirements in sensor networks. In this paper, we analyze the challenges of supporting QoS in traffic at the network and link layers.

II. QOS CHALLENGES IN WSN

Some characteristics of WSNs cause some limitations for QoS support. These limitations include [14,15,16]:

A.. Limitation of the resources

This includes energy, bandwidth, memory, processing power and transmission power. Therefore, QoS support methods need to be energy efficient, simple, and computationally light. They also need to provide bandwidth guarantees.

B. Redundancy of data

In WSN, it is possible to have redundancy of data which can improve data reliability, sensing, transmitting and processing consume more energy. Reliable data aggregation decreases the data redundancy but creates difficulty in QoS design.

C. Dynamics in Network

Node mobility, node and link failure may change the network topology. Since the nodes are dynamic in nature, can also result in frequent change of the network topology. Such dynamicity complicates proper design of QoS support techniques.

D. Balancing the Energy

Wireless sensor nodes have different types and periods of activities. Some nodes have to remain active for long period of time while others have low activity and are mostly in sleep mode. Being in active mode requires energy. Therefore, the longer the active period, the more energy is spent. This may result in energy depletion of some of the active nodes and create holes in networks. An effective energy balancing and distribution mechanism can greatly increase network lifetime.

E. Variation in Sampling Frequency

WSN applications have different requirements in terms of sampling rate of various sensors. Due to this, sampling rate directly affects energy consumption and data quality. Designing a QoS mechanism to satisfy both network lifetime and high data quality would be challenging task.

III. SUPPORTING QOS IN SENSOR NETWORKS

The network and link layers of the communication protocol have been the focus of researchers for improving energy utilization of the sensors. Especially in wireless sensor networks, new energy-conscious routing algorithms and medium access arbitration have been designed to reduce the energy consumption.

Before getting to the detailed analysis of the QoS issues in wireless sensor networks, it is important to differentiate between QoS objectives and constraints. Minimizing the response time is one of the QoS attribute which is common in all type of networks. Supporting the traffic is one of the QoS reruirement which is more difficult. Obtaining QoS requirements in a resource-constrained environment is a challenging task. In this section, we focus on the the technical issues for managing QoS constrained traffic in wireless networks. As an initial step we relate the energy-aware QoS in general mobile adhoc networks and state the suitability of the developed techniques to wireless sensor networks.

A..QoS in General Wireless Networks

QoS routing is usually performed through resource reservation in a connection-oriented communication in order to meet the QoS requirements for each individual connection. While many mechanisms have been proposed for routing QoS constrained multimedia data in wire based networks [18][19][20][21][22], they cannot be directly applied to wireless networks due to intrinsic characteristics of wireless environments affecting link quality and to the limited resources, such as bandwidth. Therefore various protocols have been proposed for QoS routing in wireless networks, taking the dynamic nature of the network into account [23][24][25][26][27].

Some of the protocols consider the imprecise state information while determining the routes [23][24]. CEDAR is one of the QoS aware protocol, that uses the idea of core nodes of the network while determining the paths [25]. QoS path can be found using the network core. However, if any node in the core is broken, it will cost more in terms of resource usage to reconstruct the core. Lin [26] and Zhu et al. [27] have proposed QoS routing protocols specifically designed for TDMA-based ad-hoc networks. Both protocols can build a QoS route from a source to destination with reserved bandwidth. The bandwidth calculation is done in a distributed fashion. While wireless sensor networks are also limited in bandwidth, the use of reservation based protocols for supporting QoS constrained traffic will be impractical unless the network follows a continuous data delivery model. On the other hand, applications that need regular delivery of QoS constrained data are not expected to employ sensor networks due to the lack of sufficient resources, in particular energy and bandwidth, to handle such demanding QoS traffic. In addition, the nature of sensor networks poses unique challenges compared to general wireless networks and thus requires special attention.

B. Sleep Scheduling in Wireless Network

Each sensor unit is battery powered and has limited processing, communication, and storage capabilities. Thus, for saving power at each sensor plays a vital role in extending the lifetime of a WSN [18]. As WSNs are usually closely organized, some sensors can be put into sleep, while other sensors remain active for the sensing, without sacrificing the network QoS by careful sleep scheduling. S leep scheduling techniques have been widely used to enhance the lifetime of WSNs, through revolving the roles of active and inactive sensors [19].

In this paper, we study the sleep scheduling schemes of the node based on a widely used static disk model for WSNs, where heterogeneous sensors are distributed with a stationary sink located at the center. A Sleep Scheduling algorithm is introduced and analyzed for enhancing the lifetime and energy efficiency in WSNs. The algorithm partitions the network into several levels according to the average distance among the nodes, that can be derived from the basic network parameters such as the node density and the sensor transmission range. The sensors have different lifetime due to imbalanced information dissemination rate in a consistently deployed wireless networks. Assigning hop based sleeping probabilities for sensors lightens this situation and as a result, network lifetime and energy efficiency will be increased.

C. QoS Challenges in Sensor Networks

While sensor networks inherit most of the QoS issues from the general wireless networks, they have some unique challenges. The following is an outline of design considerations for handling QoS traffic in wireless sensor networks:

Limitation of Bandwidth: A typical issue for general wireless networks is securing the bandwidth which is needed to achieve the required QoS. Limitation of Bandwidth is a most important issue for wireless sensor networks. Dedicating available bandwidth solely to QoS traffic will not be acceptable. A transaction in image/video quality may be necessary to hold non-real-time traffic. Using multiple independent routes simultaneously will sometime need to split the traffic and allow for meeting the QoS requirements. Setting independent routes for the nodes can be a complex and challenging in sensor networks due energy constraints, limited computational resources and potential increase in collisions among the transmission of sensors.

Removal of redundancy:

The sensor networks are characterized with high redundancy in the data. Elimination of redundant data messages in unconstrained traffic is easy because simple aggregation functions would be suffice. Combining system and sensor level rules may be necessary to make aggregation of QoS data computationally feasible. Another consideration is the amount of QoS traffic at a particular moment. For low traffic it could be more efficient to cease data aggregation since the overhead would become dominant.

Trade-off in Energy and delay:

The use of multi hop routing is one of the standard in wireless network thourh the transmission power of radio is proportional to the distance squared or even higher order in noisy environments. Even though, the increase in the number of hops reduces the energy consumed for data collection, the accumulation of packet delay may increase. The increase in the number of hops can, not only slow down packet delivery but also complicate the analysis in handling of delay-constrained traffic. Therefore, it is expected that QoS routing of sensors have to sacrifice energy efficiency to meet delivery requirements. Redundant routing of data may be unavoidable to cope with the typical high error rate in wireless communication, moreover complicating the trade-off between energy consumption and delay in delivery of packet.

Limitation of Buffer size:

Sensor nodes are usually constrained in processing and storage capabilities. Multi hop routing depends on intermediate relaying nodes for storing incoming packets and to forward it to the next hop. A small buffer size is sufficient, whereas buffering of multiple packets has some advantages in wireless sensor networks. Initially, the transition of the radio circuitry between transmission and reception modes consumes more energy [6] and thus it is advantageous to receive many packets prior to forwarding them. The limitation of buffer size may increases the delay that packets incur while traveling on different routes and even on the same route.

Support of multiple traffic types:

Heterogeneous set of sensors raises multiple technical issues in data routing. For instance, some applications might require a different combination of sensors for monitoring temperature, and pressure of the surrounding environment. The sensors detects the motion through acoustic and captures the image or video tracking of moving objects. These special sensors are either deployed independently or these functionalities can be added on the normal sensors to be used on demand. Reading generated data from these sensors can be at different rates, different quality of service constraints and multiple data delivery models. Therefore, heterogeneous environment makes data routing more challenging.

D. Survey of QoS Routing

QoS objectives has not been uncommon for data routing in sensor networks, e.g. [5][10], very little attention has been made to QoS constrained traffic. Recently few research projects have started to emerge addressing the support of QoS requirements in wireless sensor networks. The work published in this area falls into two categories. The first category focuses on the energy and delay trade-off without much consideration to the other issues. The second strives to spread traffic in order to effectively boost the bandwidth and lower the delay.

SAR: Sequential Assignment Routing (SAR) is one of the protocol for sensor networks that includes a notion of QoS in its routing decisions [1][5]. It is a table-driven, multi-path approach used to achieve energy efficiency and fault tolerance. The SAR protocol supports only QoS objectives. By taking QoS metrics and available energy resources on each path and priority level of each packet, the tree is created at one hop neighbor of the sink. By using these trees, multiple paths from sink to sensors are formed, where only one is actually used keeping the rest as backup. By enforcing the routing table, consistency between upstream and downstream nodes on each path is done to recover from failure. Any local failure causes an automatic path restoration procedure. Simulation results show that SAR offers less power consumption than the minimum-energy metric algorithm, that focuses only on the energy consumption of each packet without considering its priority. SAR maintains several paths from nodes to sink. Although, this allows fault-tolerance and easy recovery, the protocol suffers from the overhead of maintaining the tables and states at each sensor node especially when the number of nodes is huge.

Energy-Aware QoS Routing Protocol: A fairly new QoS aware protocol for sensor networks is proposed by Akkaya and Younis [28]. Real-time traffic is generated by imaging sensors. The proposed protocol extends the routing approach in [10] 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' energy reserve, transmission energy and other communication parameters.

A class based Queuing model is used to support both best effort and real-time traffic at the same time. The queuing model allows service sharing for real-time and non-real-time traffic. 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 redrawn from [28]. 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.

IV. SOME OPEN RESEARCH DIRECTIONS

Though various techniques have been found in literatures for QoS support in WSNs, there are still many problems to be solved for providing QoS in WSNs. Here we highlight some of the issues as directions of researches in the near future. Most of the sensor network models assume that the sensor nodes and the sink are stationary in nature. However, there exist certain scenarios, for example, in military environment, the sensor nodes and the sink will be made mobile. Also, the topology of the network may also keep on dynamically changing. Therefore, efficient routing protocols are required to address mobility and dynamicity of the wireless sensor network.[17] The deployment of heterogeneous multimedia sensor nodes and providing the QoS support to those resource constraint sensor nodes is another possible area of research in wireless sensor networks. Combining the wireless sensor network to Internet, to enable global information sharing, is also an open area of research, where the user's application will access the sink node through Internet for the needful data analysis. So incorporating the secure data routing is also an important aspect to be considered. Again providing QoS support in such an environment demands much contribution from the research community. Different services may demand different levels of QoS from the network. Depending on the requirements of the applications, the network should be able to adjust dynamically to the QoS levels and provide Service Differentiation based Quality of Service. This is another open area where effort may be put.[17]

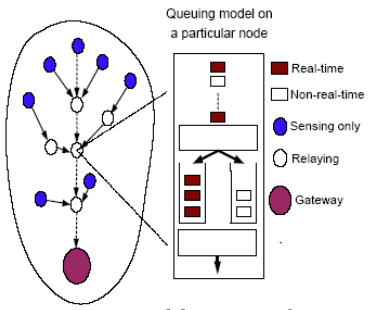

Fig. 1: Queuing model in a particular sensor node

Table 1. Comparison of QoS aware routing protocols in WSNs

Routing Protocol	Mobility	Energy Aware	Data Ag-gregation	QoS	Multipath	Query Based	Position Awareness
SAR	No	Yes	Yes	Yes	No	Yes	No
Minimum Cost Forwarding Protocol	No	No	No	Yes	No	No	No
An Energy Aware Routing Protocol	No	Yes	No	Yes	No	No	No
SPEED	No	No	No	Yes	Yes	Yes	No
MMSEED	No	No	No	Yes	Yes	Yes	No
ReInForM	No	No	No	Yes	Yes	No	No
Mobicast	Yes	Yes	No	Yes	No	Yes	Yes
DAST	No	Yes	Yes	Yes	No	No	No

Localized Packet Delivery inside the Wireless Sensor Network maintains the QoS demands of the applications is another new area of research. Wireless links are always vulnerable to different security attacks and also signal interference probability is very high. Thus providing required QoS under all sorts of constraints of Wireless Sensor Networks is a very challenging task[17]

V. CONCLUSION

Some new routing protocols have been proposed for wireless sensor networks in recent years. Most of these routing protocols considers energy efficiency as the ultimate objective, since energy is a very scarce resource for sensor nodes. Moreover, the introduction of imaging and video sensors has posed additional challenges. Transmission of imaging data and video streams requires both energy and QoS aware routing in order to ensure efficient usage of the sensors and effective access to the gathered measurements.

In this paper, we have analyzed the technical issues for supporting QoS constrained traffic and energy saving in wireless sensor networks. In addition we have reported on the state of the research in energy-aware QoS network and link layer protocols for sensor networks.

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