On Handling QoS Traffic in Wireless Sensor Networks

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***Abstract**. Many new routing and MAC layer protocols have been proposed for wireless sensor networks tackling the issues raised by the resource constrained unattended sensor nodes in large-scale deployments. The majority of these protocols considered energy efficiency as the main objective and assumed data traffic with unconstrained delivery requirements. However, the growing interest in applications that demand certain end-to-end performance guarantees and the introduction of imaging and video sensors have posed additional challenges. Transmission of data in such cases 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. We report on progress make to-date and outline open research problems.*

1 Introduction

Recent technological breakthroughs in ultra-high integration and low-power electronics have enabled the development of tiny battery-operated sensors [1-4]. 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. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. The sensor sends such collected data via the radio transmitter, to a command center (sink) either directly or through a data concentration center (a gateway). The gateway can perform fusion of the sensed data in order to filter out erroneous data and anomalies and to draw conclusions from the reported data over a period of time.

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. Networking unattended sensor nodes is expected to have significant impact on the efficiency of many military and civil applications, such as disaster management, combat field surveillance, and security. In disaster management situations such as earthquakes, sensor networks can be used to selectively map the affected regions directing emergency response units to survivors. In military situations, sensor networks can be used in surveillance missions and can be used to detect moving targets, chemical gases, or presence of micro-agents. Sensors in such environments are energy constrained and their batteries cannot be recharged. Therefore, designing energy-aware algorithms becomes 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 limit 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 including network and link layers. Current research on routing in wireless sensor networks mostly focused on protocols that are energy aware to maximize the lifetime of the network, are scalable to accommodate a large number of sensor nodes, and are tolerant to sensor damage and battery exhaustion [7][8][9][10]. In addition, medium access 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].

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. Consider the following scenario: In a battle environment in order to identify a target, we should employ imaging 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 gateway. 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.

Energy-aware QoS routing in sensor networks will ensure guaranteed bandwidth (or delay) 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 and survey current state of the research by pointing out open issues.

In the balance of this paper, we will briefly summarize the system architecture design issues for sensor networks and their implications on data routing and medium access control in section 2. We analyze the complexity of handling QoS requirements in sensor networks and discuss progress made in the research community in section 3. We outline open research issues and directions for future research in section 4. Finally, we conclude the paper with a summary in section 5.

2. System Architecture and Design Issues

Depending on the application, different architectures and design goals/constraints have been considered for sensor networks. Since the performance of a routing and MAC protocols are closely related to the architectural model, in this section we strive to capture architectural design issues and highlight their implications. Later we will analyze the complexity of supporting QoS traffic in light of these design variations. A summary of design issues is given in Table 1.

Network Dynamics: There are three main components in a sensor network. These are the sensor nodes, sink and monitored events. Aside from the very few setups that utilize mobile sensors [14], most of the network architectures assume that sensor nodes are stationary. On the other hand, supporting the mobility of sinks or cluster-heads (gateways) is sometimes deemed necessary [15]. Routing messages from or to moving nodes is more challenging since route stability becomes an important optimization factor, in addition to energy, bandwidth etc. The sensed event can be either dynamic or static depending on the application [16]. For instance, in a target detection/tracking application, the event (phenomenon) is dynamic whereas forest monitoring for early fire prevention is an example of static events. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the sink.

Node Deployment: Another consideration is the topological deployment of nodes. This is application dependent and affects the performance of the routing protocol. The deployment is either deterministic or self-organizing. In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. In addition, collision among the transmissions of the different nodes can be minimized through the pre-scheduling of medium access. However in self-organizing systems, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner [5][17][10][18]. In that infrastructure, the position of the sink or the cluster-head is also crucial in terms of energy efficiency and performance. When the distribution of nodes is not uniform, optimal clustering becomes a pressing issue to enable energy efficient network operation.

Node Communications: During the creation of an infrastructure, the process of setting up the routes is greatly influenced by energy considerations. Since the transmission power of a wireless radio is proportional to distance squared or even higher order in the presence of obstacles, multi-hop routing will consume less energy than direct communication. However, multi-hop routing introduces significant overhead for topology management and medium access control. Direct routing would perform well enough if all the nodes were very close to the sink [17]. Most of the time sensors are scattered randomly over an area of interest and multi-hop routing becomes unavoidable. Arbitrating medium access in this case becomes cumbersome.

Data Delivery Models: Depending on the application of the sensor network, the data delivery model to the sink can be continuous, event-driven, query-driven and hybrid [16]. In the continuous delivery model, each sensor sends data periodically. In event-driven and query-driven models, the transmission of data is triggered when an event occurs or a query is generated by the sink. Some networks apply a hybrid model using a combination of continuous, event-driven and query-driven data delivery. The routing and MAC protocols are highly influenced by the data delivery model, especially with regard to the minimization of energy consumption and route stability. For instance, it has been concluded in [19] that for a habitat monitoring application where data is continuously transmitted to the sink, a hierarchical routing protocol is the most efficient alternative. This is due to the fact that such an application generates significant redundant data that can be aggregated on route to the sink, thus reducing traffic and saving energy. In addition, in continuous data delivery model time-based medium access can achieve significant energy saving since it will enable turning off sensors' radio receivers [11]. CSMA medium access arbitration is a good fit for event-based data delivery models since the data is generated sporadically.

Node Capabilities: In a sensor network, different functionalities can be associated with the sensor nodes. In early work on sensor networks [4][20][21], all sensor nodes are assumed to be homogenous, having equal capacity in terms of computation, communication and power. However, depending on the application a node can be dedicated to a particular special function such as relaying, sensing and aggregation since engaging the three functionalities at the same time on a node might quickly drain the energy of that node. Some of the hierarchical protocols proposed in the literature designate a cluster-head different from the normal sensors. While some networks have picked cluster-heads from the deployed sensors [17][22][23], in other applications a cluster-head is more powerful than the sensor nodes in terms of energy, bandwidth and memory [10][14]. In such cases, the burden of transmission to the sink and aggregation is handled by the cluster-head.

Data Aggregation/Fusion: Since sensor nodes might generate significant redundant data, in some applications similar packets from multiple nodes can be aggregated so that the number of transmissions would be reduced. Data aggregation is the combination of data from different sources by using functions such as *suppression* (eliminating duplicates), *min, max* and *average* [24]. Some of these functions can be performed either partially or fully in each sensor node, by allowing sensor nodes to conduct in-network data reduction [20][22][25]. Recognizing that computation would be less energy consuming than communication [17], substantial energy savings can be obtained through data aggregation. This technique has been used to achieve energy efficiency and traffic optimization in a number of routing protocols. In some network architectures, all aggregation functions are assigned to more powerful and specialized nodes [14]. Data aggregation is also feasible through signal processing techniques. In that case, it is referred as *data fusion* where a node is capable of producing a more accurate signal by reducing the noise and using some techniques such as *beamforming* to combine the signals [17]. Data aggregation makes medium access control complex since redundant packets will be eliminated and such elimination will require instantaneous medium access arbitration. In such case, only CSMA and CDMA-based MAC protocols are typically applicable leading to an increase in energy consumption.

Design Issue	Primary Factors
Network Dynamics	mobility of node, target, and sink
Node Deployment	deterministic or ad Hoc
Node Communications	single-hop or multi-hop
Data Delivery Models	continuous, event-driven, query-driven, or hybrid
Node Capabilities	multi- or single function; homogeneous or heterogeneous capabilities
Data Aggregation/Fusion	in-network (partially or fully) or out-of-network

Table 1: Architectural Design Issues

3 Supporting QoS in Sensor Networks

The network and link layers of the communication protocol stack have been the focus of researchers for improving energy utilization. Especially in wireless sensor networks, new energy-conscious routing algorithms and medium access arbitration have been designed. However, little research has been done on supporting QoS constrained traffic. Although there has been some research on QoS routing for mobile ad hoc networks, it has not been studied in the context of wireless sensor networks.

Before getting to the detailed analysis of the QoS issues in wireless sensor networks, it is important to differentiate between QoS objectives and constraints. Having design or operational goals in terms of QoS attributes, e.g. minimizing end-to-end delay (response time), is very common in all types of networks. Supporting traffic that is subject to QoS requirements is generally more difficult. Meeting QoS requirements in a resource-constrained environment, such as sensor networks, is exceptionally challenging.

In this section, we analyze the technical issues for handling QoS constrained traffic in wireless sensor networks and report on the state of the research. First we outline the research effort related to energy-aware QoS in general mobile ad hoc networks and comment on the appropriateness of the developed techniques to wireless sensor networks. Section 2.2 lists the main challenges of supporting QoS traffic in wireless sensor networks. Finally we survey published and on-going research on routing and MAC layer protocols for QoS sensor data.

3.1 QoS in General Wireless Networks

While contemporary best-effort routing approaches address-unconstrained traffic, 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 [26][27][28][29][30], they cannot be directly applied to wireless networks due to inherent characteristics of wireless environments affecting link quality and to the limited resources, such as bandwidth. Therefore several new protocols have been proposed for QoS routing in wireless ad-hoc networks taking the dynamic nature of the network into account [31][32][33][34][35].

Some of the proposed protocols consider the imprecise state information while determining the routes [31][32]. CEDAR is another QoS aware protocol, which uses the idea of core nodes (dominating set) of the network while determining the paths [33]. Using routes found through the network core, a QoS path can be found. However, if any node in the core is broken, it will cost too much in terms of resource usage to reconstruct the core. Lin [34] and Zhu et al. [35] 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 hop-by-hop 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. The next subsection discusses such challenges.

3.2 QoS Challenges in Sensor Networks

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

- *Bandwidth limitation*: A typical issue for general wireless networks is securing the bandwidth needed for achieving the required QoS. Bandwidth limitation is going to be a more pressing issue for wireless sensor networks. Traffic in sensor networks can be burst with a mixture of real-time and non-real-time traffic. 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. In addition, simultaneously using multiple independent routes will be sometime needed to split the traffic and allow for meeting the QoS requirements. Setting up independent routes for the same flow can be very 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*: As discussed in section 1.1, sensor networks are characterized with high redundancy in the generated data. For unconstrained traffic, elimination of redundant data messages is somewhat easy since simple aggregation functions would suffice. However, conducting data aggregation for QoS traffic is much more complex. Comparison of images and video streams is not computationally trivial and can consume significant energy resources. A combination of system and sensor level rules would be necessary to make aggregation of QoS data computationally feasible. For example, data aggregation of imaging data can be selectively performed for traffic generated by sensors pointing to same direction since the images may be very similar. Another factor of consideration is the amount of QoS traffic at a particular moment. For low traffic it may be more efficient to cease data aggregation since the overhead would become dominant. Despite the complexity of data aggregation of imaging and video data, it can be very rewarding from a network performance point-of-view given the size of the data and the frequency of the transmission.

- *Energy and delay trade-off*: Since the transmission power of radio is proportional to the distance squared or even higher order in noisy environments or in the non-flat terrain, the use of multi-hop routing is almost a standard in wireless sensor networks. Although the increase in the number of hops dramatically reduces the energy consumed for data collection, the accumulative packet delay magnifies. Since packet queuing delay dominates its propagation delay, the increase in the number of hops can, not only slow down packet delivery but also complicate the analysis and the handling of delay-constrained traffic. Therefore, it is expected that QoS routing of sensor data would have to sacrifice energy efficiency to meet delivery requirements. In addition, redundant routing of data may be unavoidable to cope with the typical high error rate in wireless communication, further complicating the trade-off between energy consumption and delay of packet delivery.

- *Buffer size limitation*: Sensor nodes are usually constrained in processing and storage capabilities. Multi-hop routing relies on intermediate relaying nodes for storing incoming packets for forwarding to the next hop. While a small buffer size can conceivably suffice, buffering of multiple packets has some advantages in wireless sensor networks. First, the transition of the radio circuitry between transmission and reception modes consumes considerable energy [6] and thus it is advantageous to receive many packets prior to forwarding them. In addition, data aggregation and fusion involves multiple packets. Multi-hop routing of QoS data would typically require long sessions and buffering of even larger data, especially when the delay jitter is of interest. The buffer size limitation will increase the delay variation that packets incur while traveling on different routes and even on the same route. Such an issue will complicate medium access scheduling and make it difficult to meet QoS requirements.

- *Support of multiple traffic types*: Inclusion of heterogeneous set of sensors raises multiple technical issues related to data routing. For instance, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures and capturing the image or video tracking of moving objects. These special sensors are either deployed independently or the functionality can be included on the normal sensors to be used on demand. Reading generated from these sensors can be at different rates, subject to diverse quality of service constraints and following multiple data delivery models, as explained earlier. Therefore, such a heterogeneous environment makes data routing more challenging.

3.3 Survey of QoS Routing

While having QoS objectives has not been uncommon for data routing in sensor networks, e.g. [5][10], very little attention has been paid to QoS constrained traffic. Recently few research projects have started to emerge addressing the support of QoS requirements in wireless sensor networks. In this subsection, we survey the state of the research summarizing published work and highlighting the subset of QoS issues being addressed. In summary, the work published so far falls into two categories. 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 order to effectively boost the bandwidths and lower the delay. The following is a more elaborate summary of these approaches.

SAR: Sequential Assignment Routing (SAR) is the first protocol for sensor networks that includes a notion of QoS in its routing decisions [1][5]. It is a table-driven multi-path approach striving to achieve energy efficiency and fault tolerance. The SAR protocol supports only QoS objectives. It creates trees rooted at one-hop neighbors of the sink by taking QoS metrics, available energy resources on each path and priority level of each packet into consideration. By using the created trees, multiple paths from sink to sensors are formed, of which only one is actually used keeping the rest as backup. Failure recovery is done by enforcing routing table consistency between upstream and downstream nodes on each path. Any local failure causes an automatic path restoration procedure. Simulation results show that SAR offers less power consumption than the minimum-energy metric algorithm, which focuses only the energy consumption of each packet without considering its priority. SAR maintains multiple 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. SAR also does not use redundant routes to split the load and effectively boost the bandwidth.

Energy-Aware QoS Routing Protocol: A fairly new QoS aware protocol for sensor networks is proposed by Akkaya and Younis [36]. 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, 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-

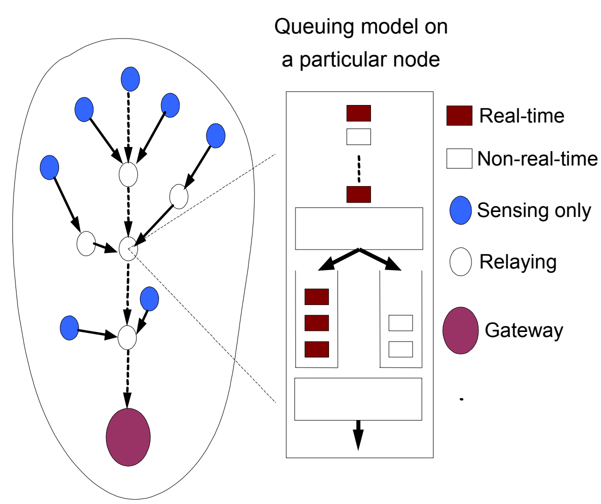

Fig. 1: Queuing model in a particular sensor node

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 redrawn from [36]. 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.

Simulation results show 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, which does not provide flexible adjusting of bandwidth sharing for different links. The protocol is extended in [37] by assigning a different *r*-value for each node in order to achieve a better utilization of the links.

SPEED: A QoS routing protocol for sensor networks that provides soft real-time end-to-end guarantees is described in [38]. The protocol requires each node to maintain information about its neighbors and uses geographic forwarding to find the paths. In addition, SPEED strive to ensure a certain speed for each packet in the network so that each application can estimate the end-to-end delay for the packets by considering the distance to the sink and the speed of the packet before making the admission decision. Moreover, SPEED can provide congestion avoidance when the network is overloaded.

The routing module in SPEED is called Stateless Geographic Non-Deterministic forwarding (SNFG) and works with four other modules at the network layer, as shown in Fig. 2, redrawn from [38]. The beacon exchange mechanism collects information about the nodes and their location. Delay estimation at each node is basically made by calculating the elapsed time when an ACK is received from a neighbor as a response to a transmitted data packet. By looking at the delay values, SNGF selects the node, which meets the speed requirement. If such a node cannot be found, the *relay ratio* of the node is checked. The Neighborhood Feedback Loop module is responsible for providing the relay ratio, which is calculated by looking at the miss ratios of the neighbors of a node (the nodes which could not provide the desired speed) and is fed to the SNGF module. If the relay ratio is less than a randomly generated number between 0 and 1, the packet is dropped. And finally, the backpressure-rerouting module is used to prevent voids, when a node fails to find a next hop node, and to eliminate congestion by sending messages back to the source nodes so that they will pursue new routes.

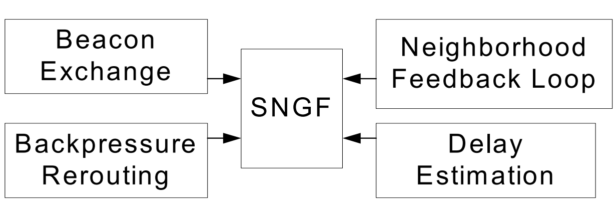

Fig. 2: Routing components of SPEED

When compared to Dynamic Source Routing (DSR) [39] and Ad-hoc on-demand vector routing (AODV) [40], SPEED performs better in terms of end-to-end delay and miss ratio. Moreover, the total transmission energy is less due to the simplicity of the routing algorithm, i.e. control packet overhead is less, and to the even traffic distribution. Such load balancing is achieved through the SNGF mechanism of dispersing packets into a large relay area. SPEED does not consider any energy metric in its routing protocol.

3.4 MAC Level Support

Several MAC protocols were proposed for wireless networks based on contention and carrier sense [41][42]. However, such protocols aim at maximizing the throughput and do not provide any real-time guarantee. In order to provide QoS guarantees such as bounded delay, many protocols have employed special real-time packet scheduling mechanisms [43][44][45][46]. However, these protocols introduce a significant amount of control packet overhead, which can be a burden for the limited energy resources of a sensor node and therefore are not applicable to sensor networks.

While many energy-aware MAC protocols have been proposed for sensor networks [13][47][48], very little research has been done to combine real-time scheduling techniques and energy-awareness. Recently, Caccamo et al. have proposed an implicit prioritized access protocol for sensor networks which utilizes Earliest Deadline First (EDF) scheduling algorithm in order to ensure timeliness for real-time traffic [49]. The idea is to take advantage of the periodic nature of the sensor data traffic to create a schedule rather than using control packets for channel reservation. A sensor network architecture composed of several hexagonal cells is considered. In order to avoid channel interferences, 7 different frequency channels are used. Within each cell, all the nodes are assumed to be fully connected so that there will be no hidden channel problem. Enabling multicast within each cell provides elimination of redundant data since only one message is transmitted out of the cell after intra-cell message exchanges. Simulation results show that the protocol performs better in terms of throughput and average delay in heavy load conditions when compared to CSMA/CA with RTS/CTS option disabled.

RAP [50] is another project that considers a real-time scheduling policy for sensor networks. RAP is a communication architecture for sensor networks that proposes velocity-monotonic scheduling in order to minimize deadline miss ratios for packets. Each packet is put to a different FIFO queue based on their requested velocity, i.e. the deadline and closeness to the gateway. This ensures a prioritization in the MAC layer. An extension of IEEE 802.11 [51] is used along with such prioritization.

Power-aware reservation based MAC (PARMAC) [52] is an energy-aware protocol primarily designed for mobile ad hoc networks. However, it is assumed in the paper that the nodes are not moving. Therefore, this MAC protocol can be applied to sensor networks as well. The network is divided into grids and in each grid each node is assumed to reach all the other nodes within the grid area. Time is divided into fixed frames where each frame is composed of Reservation Period (RP) and Contention Free Period (CFP). In each RP, nodes within a grid cell exchange 3 messages to reserve the slots for data transmission and reception. Data is then sent in CFP. If the reservation can be done before the deadline for real-time packets, then this means delay bounds can be provided. The protocol saves energy by minimizing the idle time of the nodes and allowing the nodes to sleep during CFP. Moreover, the control packet overhead and packet retransmissions are minimal achieving significant energy savings.

4 Open Research Issues

Overcoming bandwidth limitation, effective energy and delay trade-off, handling buffer size limitation, supporting multiple traffic types and the removal of redundancy have been identified as the main technical challenges for supporting QoS requirements in wireless sensor networks. Few research projects have started to tackle only a subset of these issues, leaving lots of room for future research. End-to-end delay bounds have been the main QoS requirement considered so far, leaving out the consideration of delay jitter. Meeting delay jitter constraints is a much tougher problem that yet to be investigated. In addition, it is interesting to analyze the handling of QoS traffic through data-centric routing approaches. The large data size of imaging/video data combined with the complexity of aggregation makes the problem increasingly challenging.

Another interesting issue for QoS routing protocols is the consideration of node mobility. Most of the current protocols assume that the sensor nodes and the sink are stationary. However, there might be situations such as battle environments where the sink and possibly the sensors need to be mobile. In such cases, the frequent update of the position of the command node and the sensor nodes and the propagation of that information through the network may excessively drain the energy of nodes. Clever QoS routing and MAC protocols are needed in order to handle the overhead of mobility and topology changes in such energy-constrained environment.

Other possible future research for routing protocols includes the integration of sensor networks with IP-based networks (e.g. Internet). Most of the applications in security and environmental monitoring require the data collected from the sensor nodes to be transmitted to a server so that further analysis can be done. On the other hand, the requests from the user could be made to the sink through Internet. Since the routing requirements of each environment are different, further research is necessary for handling QoS requirements under these kinds of situations.

5 Conclusion

Several new routing protocols have been proposed for wireless sensor networks in recent years. Almost all of these routing protocols considered energy efficiency as the ultimate objective since energy is a very scarce resource for sensor nodes. However, 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 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. Finally, we presented some open research issues and directions for future work.

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