QoS Support in Wireless Sensor Networks

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Abstract – Wireless sensor networks (WSNs) are required to provide different levels of Quality of Service (QoS) based on the type of applications. Providing QoS support in wireless sensor networks is an emerging area of research. Due to resource constraints like processing power, memory, bandwidth, and power sources in sensor networks, QoS support in WSNs is a challenging task. In this paper, we discuss QoS perspectives and goals, QoS requirements in WSN, metrics and parameters, challenges to support QoS in WSN and finally highlight some open issues and future directions of research for providing QoS in WSN.

Index Terms – Wireless Sensor Network (WSN), Quality of Service (QoS), QoS perspectives, goals, QoS requirements.

1. INTRODUCTION

In recent years, the rapid development in miniaturization; low power wireless communication, microsensor, and microprocessor hardware; small-scale energy supplies in conjunction with the significant progress in distributed signal processing, ad hoc networks protocols, and pervasive computing have made wireless sensor networks (WSNs) a new technological vision [10]. As the Internet has revolutionized our life via the exchange of diverse forms of information readily among a large number of users, WSNs may, in the near future, be equally significant by providing information regarding the physical phenomena of interest and ultimately being able to detect and control them or enable us to construct more accurate models of the physical world. Potential applications of WSNs include environmental monitoring, industrial control, battlefield surveillance and reconnaissance, home automation and security, health monitoring, and asset tracking.

While a lot of research has been done on some important aspects of WSNs such as architecture and protocol design, energy conservation, and location, supporting Quality of Service (QoS) in WSNs is still a largely unexplored research field. This is mainly because WSNs are very different from traditional networks.

It is well known that QoS is an overused term with various meanings and perspectives [1]. Different technical communities may perceive and interpret QoS in different ways. In the application communities, QoS generally refers to the quality as perceived by the user/application while in the networking community, QoS is accepted as a measure of the service quality that the network offers to the applications/users. In [8] QoS is characterized as a set of service requirements to be met when transporting a packet stream from the source to its destination. In this scenario, QoS refers to an assurance by the internet to provide a set of measurable service attributes to the end-t0-end users/applications in terms of delay, jitter, available bandwidth, and packet loss. These two QoS perspectives can be demonstrated via a simple model [1] shown in figure 1.

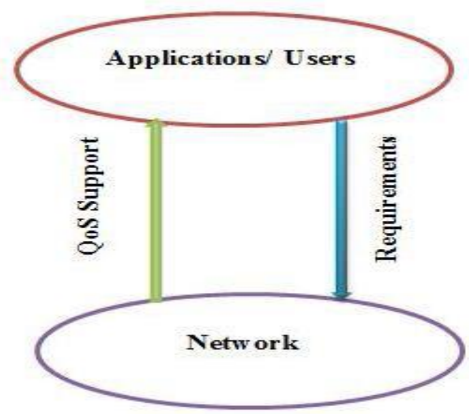

Figure 1. A simple QoS model

In this model, the application/users are not concerned with how the network manages its resources to provide the QoS support. They are only concerned with the services that networks provide which directly impact the quality of the application. From the network perspective, the network's goal is to provide the QoS services while maximizing network resource utilization. To achieve this goal, the network is required to analyze the application requirements and deploy various network QoS mechanisms.

QoS requirements in traditional data networks mainly result from the rising popularity of end-to-end bandwidth-hungry multimedia applications. Different multimedia applications have different QoS requirements expressed in terms of end to-end QoS parameters. The network is thereby required to provide better services than original best effort service, such as guaranteed services (hard QoS) and differentiated services (soft QoS), for end-to-end users/applications. The researchers have pursued end-to-end QoS support using a large number of mechanisms and algorithms in different protocol layers while maximizing bandwidth utilization. At the same time, different types of networks may impose specific constraints on the QoS support due to their particular characteristics. For example, the bandwidth constraint and dynamic topology of mobile ad hoc networks make the QoS support in such networks much more challenging than in others.

However, QoS requirements generated by the applications of WSNs may be very different and traditional end-to-end QoS parameters may not be sufficient to describe them. As a result, some new QoS parameters are desired for the measurement of the delivery of the sensor data in an efficient and effective way. Further, by measuring these parameters, network designers are also able to investigate which QoS architecture or mechanism can be exploited to provide QoS support for the applications [5].

2. QoS METRICS (PARAMETERS)

In this section we present the metrics that quantify the QoS requirements. These include delay, jitter, packet loss, throughput, energy consumption, bandwidth utilization, network lifetime, and cost [9][20].

Delay- it indicates the length of time taken for a packet to travel from source to destination. It represents average data delay an application experiences when transmitting data. This parameter is intrinsic to communication, since end points are distant and information will consume some time to reach the other side. Delay is also referred to as latency. Delay time can be increased if the packets face long queues in the network (congestion) or crosses a direct route to avoid congestion. The delay can be measured either one-way (total time from source that sends a packet to the destination that receive it) or round trip (one way latency from source to destination plus one way latency from destination to source). The round trip delay is relatively accurate way of measuring delay, because it excludes the amount of time that a destination system spends processing the packet. It only sends a response back when it receives a packet. Delay has to be minimum.

Jitter- it is the delay variation and is introduced by the variable transmission of the delay of the packets over the network. This can occur because of router's internal queues behavior in certain circumstances (eg. Flow congestion), routing changes etc. this parameter can seriously affect the quality of streaming audio and/or video. To handle jitter, it is needed to collect packets and hold them long enough until the slowest packet arrives in time, rearranging them to be played in correct sequence.

Packet loss- happens when one or more packets of the data being transported across the internet or a computer network fail to reach their destination. This loss of packets can be caused due to signal degradation, high loads on network links, packets that are corrupted being discarded or defect in network elements. Wireless Networks have higher probability of loss that is introduced by the air interface (eg. Interference caused by other systems, multiple obstacles (buildings, environment) in the path, multiple path fading etc.). Packet loss can be tolerant but only to a certain extent.

Throughput- It is the number of bits passed through a network in one second. It is the measurement of how fast the data can pass through an entity such as point or a network. So it should be maximum.

Energy consumption- This is the amount of energy consumed by the devices during the period s of transmitting, receiving, idle and sleep. Hence battery life is key parameter and hence energy consumption should be less.

Bandwidth- certain bandwidth requirements must be fulfilled. It is what the reporting of events require. Hence efficient bandwidth utilization is must.

Network lifetime-It is defined as the minimum time at which maximum number of sensors nodes are dead or shut down during a long run of simulation. So it should be long.

Cost- sometimes the sensors are deployed in large numbers to increase the efficiency of system. It is very costly to check quality of service of individual sensors used in a typical application domain Of WSN. Hence it is necessary to consider network as a whole or at least to use network in part. So cost should be low.

3. CHALLENGES for QoS SUPPORT in WSN

Since WSNs have to interact with the environment, their characteristics can be expected to be very different from other conventional data networks. Thus, while WSNs inherit most of the QoS challenges from general wireless networks, their particular characteristics pose unique challenges as follows [5],[7],[13],[21].

Severe resource constraints: The constraints on resources involve energy, bandwidth, memory, buffer size, processing capability, and limited transmission power. Among them, energy is a primary concern since energy is severely constrained at sensor nodes and it may not be feasible to replace or recharge the battery for sensor nodes that are often expected to work in a remote or inhospitable environment. As a result, these constraints impose an essential requirement on any QoS support mechanisms in WSNs.

Unbalanced traffic: In most applications of WSNs, traffic mainly flows from a large number of sensor nodes to a small subset of sink nodes. QoS mechanisms should be designed for an unbalanced QoS-constrained traffic.

Data redundancy: WSNs are characterized by high redundancy in the sensor data. However, while the redundancy in the data does help loosen the reliability/robustness requirement of data delivery, it unnecessarily spends much precious energy. Data fusion or data aggregation is a solution to maintain robustness while decreasing redundancy in the data, but this mechanism also introduces latency and complicates QoS design in WSNs.

Network dynamics: Network dynamics may arise from node failures, wireless link failures, node mobility, and node state transitions due to the use of power management or energy efficient schemes. Such a highly dynamic network greatly increases the complexity of QoS support.

Energy balance: In order to achieve a long-lived network, energy load must be evenly distributed among all sensor nodes so that the energy at a single sensor node or a small set of sensor nodes will not be drained out very soon. QoS support should take this factor into account.

Scalability: A generic wireless sensor network is envisioned as consisting of hundreds or thousands of sensor nodes densely distributed in a terrain. Therefore, QoS support designed for WSNs should be able to scale up to a large number of sensor nodes, i. e. QoS support should not degrade quickly when the number of nodes or their density increases.

Multiple sinks: Even though most of the sensor network have only single sink or base station, there can be multiple sink nodes depending on the application requirements. WSNs should be able to maintain diversified level of QoS support associated with multiple sinks or base station.

Multiple traffic types: applications might need access to heterogeneous data collected by different types of sensors with different sampling rates. This heterogeneous environment makes QoS support more complex and challenging.

Packet criticality: some data are most times very critical and it needs real time attentions. QoS mechanisms may be required to differentiate packet importance and set up a priority structure.

As a result, when an application is specified, QoS support for the network may have to take into account at least a few of the challenges described above.

4. QoS REQUIREMENTS

Wireless sensor network is a new member of wireless data networks family with some specific characteristics and requirements. A generic wireless sensor network is composed of a large number of sensor nodes scattered in a terrain of interest. Each of them has the capability of collecting data about an ambient condition, and sending data reports to a sink node. Since there exist many envisioned applications in WSNs and their QoS requirements may be very different, it is impossible for us to analyze them individually. Also, it is unlikely that there will be a "one-size-fits-all" QoS support solution for each application. So we can initially separate QoS requirements using two perspectives- *application specific and network specific.*

Application-specific QoS-

From this perspective, we may consider QoS parameters such as coverage [15], exposure [16], measurement errors, and optimum number of active sensors [14]. In brief, the applications impose specific requirements on the deployment of sensors, the number of active sensors, and the measurement precision of sensors and so on, which are directly related to the quality of applications.

Network specific QoS- From this perspective, we consider how the underlying communication network can deliver the QoS-constrained sensor data while efficiently utilizing network resources. Although we cannot analyze each possible application in WSNs, it is sufficient for us to analyze each class of applications classified by data delivery models, since most applications in each class have common requirements on the network. From the point of view of network QoS, we are not concerned with the applications that is actually carried out, we are concerned with how the data is delivered to the sink and corresponding requirements such as latency, packet loss and reliability. Generally, there are three basic data delivery models, i. e. , event-driven, query-driven, and continuous delivery models [17].

Event-driven: In this model, sensor nodes report data only if an event of interest occurs. Usually, the events are rare. Yet, when an event occurs, a burst of packets are often generated that need to be transported reliably, and usually in real-time, to a base station. The success of the network depends on the efficient detection and notification of the event that is of interest to the user. This is bound to quality and accuracy of the observation related to the observed phenomena with reliable and fast delivery of the information about the detected event. Since more than one sensor nodes will detect the event and generate related data, this type of applications are not end-to-end. Also creation of highly redundant and bursty traffic by sensors affected by the same event is very likely to be observed in event driven applications. Surveillance and target tracking can be an example for this class.

Query-driven: Query-driven data delivery model is very similar to the event-driven model with an exception: Data is pushed to the sink without any demand by the sensor nodes in event-driven model while data is requested by the sink and pushed by the sensor nodes in the query-driven model. Hence, contrary to the one-way traffic of event-driven model, two-way traffic comes into scene which consists of requests of the sink and replies of the sensor nodes. Both requests and replies must be delivered quickly and reliably for achieving higher performance in query-driven applications. Environmental control or habitat monitoring can be an example for this class.

Continuous: In this model, sensor nodes transmit the collected data at periodic intervals and can be considered as the basic model for traditional monitoring applications based on data collection. The data rates can be usually low and to save energy the radios can be turned on only during data transmissions if scalar data is collected. However, real-time data such as voice or image are delay-intolerant and requires a certain level of bandwidth. Also packet losses are tolerated in a limited threshold. For periodically collected non real-time data, latency and packet losses are tolerable. Surveillance or reconnaissance can be an example of this class.

5. QoS PROVISIONING in WSN

WSNs have two main approaches for QoS provisioning: *classic layered approach* and *cross layer approach.* Layered approach achieves QoS provisioning with protocols that operate only in one individual layer of the WSN communication protocol stack, while cross–layer approach provides the desired QoS through the simultaneous interaction of multiple layers in WSN. The outcome of both is the same: providing predictable QoS levels to users and applications and in same time lowering energy consumption. As the goal of QoS provisioning is to achieve a more deterministic network behavior, so that information carried by the network can be better delivered and network resources can be better utilized. So the successful deployment of QoS in WSNs is a challenging task because it depends on both the inherent properties of the network, as well as the physical hardware constraints of the sensor nodes [24].

6. MECHANISMS to ACHIEVE QoS in WSNs

In this section, we describe some existing mechanisms that have been proposed which allows WSNs to achieve QoS.

Topology Management: Most of the energy that is expended by a node is through transmission and sensing. To reduce the amount of energy that is consumed by a sensor node in the network, the nodes can be put to sleep mode when they are not required to sense or transmit data to their neighboring nodes. Topology management can be used to achieve this dual goal of coordinating the sleep schedules of all the nodes, such that data can still be forwarded efficiently to the sink [6]. It is able to do this by exploiting the high nodal density and high spatial correlation of the sensed data. As such, topology management helps to increase energy efficiency (and thus network lifetime) at the expense of higher latency, because nodes that are required for the data forwarding process may be in sleep mode during the transmission.

Localization: Localization provides an alternative mechanism of finding the physical locations of the sensor nodes in the network instead of making use of GPS, which is costly and infeasible indoors. It usually involves two phases [2]: (i) ranging, which is the distance estimation of the node from the sink or other nodes in the network using techniques such as signal strength, angle-of-arrival (AoA), etc; and (ii) iterative multilateration, which makes use of the range measurements from the previous phase to calculate a new location estimate. Hence, localization increases spatial accuracy, at the cost of higher overheads (and transmissions) which will reduce energy efficiency.

Controlled Mobility: One of the main causes of performance deterioration in wireless sensor networks is node mobility (due to influence from the environment) and random deployment of nodes (due to the denseness which nodes are usually deployed). As such, the resulting network topology is usually not optimized for the protocols which are designed for the network. To incorporate QoS in the sensor network, controlled mobility [18] using mobile nodes or Unmanned Autonomous Vehicles (UAVs) can be used to deploy sensor nodes more efficiently to enhance connectivity and/or coverage

Data Aggregation and/or Fusion: In data aggregation [4], data which is coming from different sources en route is combined into a single data packet. This helps to reduce redundancy caused by spatial correlation of the sensed data and minimize the number of transmissions required to forward the data back to the sink. However, as data processing is required at some (or all) of the sensor nodes in order to do aggregation, this could potentially result in higher latency, which should be taken into consideration when designing data aggregation algorithm for use in sensor networks. Data fusion is similar to data aggregation in that data of different modalities are combined before data transmission.

Network Topology: Conventional wireless sensor networks have a single centralized sink that is usually placed in a corner of the network, and all the source nodes have to send data to the sink in a predominantly unilateral direction. As a result, sensor nodes that are near the sink have to perform more data forwarding and packet transmissions, which leads to two undesired behaviors: (i) increased contention and collisions near the sink; and (ii) nodes that are near the sink will drain up their energy faster, resulting in shorter network lifetime [19]. So the use of more than one sink in a virtual multi-sink multi-path network architecture, which provides spatially diverse routes in the network such that source nodes will avoid sending all the data to one direction and cause network deterioration. This helps to improve the load distribution of the network and increases the network lifetime, at the expense of the physical deployment of more sinks.

Cross-Layer Designs: Although traditional networking paradigms promote the usage of a multi-layered protocol stack in which the different layers have minimal impact on each other, this does not lead to optimal performance. Cross layered designs such as that proposed by in [12] can help to improve network performance by sharing information across the different layers, at the cost of eliminating the interdependency between adjacent layers.

7. OPEN RESEARCH ISSUES

Here we again want to mention a simple fact to be noted is that QoS always vary from application to application. But still there are some common problems which are applicable to major areas of WSNs. 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, where the sensor nodes and the sink are required to be made mobile. Moreover, the topology of the network may also keep on changing dynamically. Therefore, efficient routing protocols are required to address mobility and dynamicity of the wireless sensor network.

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.

Integration of the wireless sensor network to Internet, to enable global information sharing, is also an open area of research. Here the user's application will access the sink node through Internet for the needful data analysis. So incorporation of secure data routing is also an important aspect to be considered. Designing of middleware for wireless sensor networks is yet another very exciting research area in Wireless Sensor Networks. 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 upon the requirements of the applications, the network should be able to dynamically adjust the QoS levels and provide Service Differentiation based Quality of Service. This is another open area where effort may be put.

Localized Packet Delivery inside the Wireless Sensor Network maintaining the Quality of Service 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 Quality of Service under all sorts of constraints of Wireless Sensor Networks is a very challenging task.

8. CONCLUSION

Few efforts have been made in the research field of QoS support in WSNs so far. Current WSNs are not only used for traditional low data-rate applications but also for more complex operations which require efficient, reliable and timely collection of large amounts of data. Moreover, they are not only composed of sensor devices which generate scalar data but also the use of video and microphone sensors are becoming common. Increasing capacities of the sensor nodes, variety of the application fields and multimodal use of sensors require efficient QoS provisioning mechanisms in WSNs. With these requirements in mind, we have focused on the perspectives, challenges, metrics, parameters and requirements of QoS for WSNs in this paper. Some exciting open issues are identified in order to stimulate more creative research in the future. Generally, QoS support is becoming more and more challenging due to our increasing desire for the connectivity to exchange information of the best quality at any time, at any location, and by any manner.

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