QoS Support in Wireless Sensor Networks: A Survey

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***Abstract*— In this paper, we assess the state of the art of Quality of Services (QoS) support in wireless sensor networks (WSNs). Unlike traditional end-to-end multimedia applications, many non-end-to-end mission-critical applications envisioned for WSNs have brought forward new QoS requirements on the network. Further, unique characteristics of WSNs, such as extremely resource-constrained sensors, large-scale random deployment, and novel data-centric communication protocols, pose unprecedented challenges in the area of QoS support in WSNs. Thus, we first review the techniques for QoS support in traditional networks, analyze new QoS requirements in WSNs from a wide variety of applications classified by data delivery models, and propose some non-end-to-end collective QoS parameters. Next, the challenges of QoS support in this new paradigm are presented. Finally, we comment on current research efforts and identify many exciting open issues in order to stimulate more research interest in this largely unexplored area.**

***Keywords*— Wireless networks, wireless sensor networks, QoS, collective QoS**

I. 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 [1][2][3]. 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 locationing, 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. Thus far, it is not entirely clear how to properly describe the services of WSNs, much less to develop approaches for QoS support.

It is well known [4] that QoS is an overused term with various meanings and perspectives. 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. For instance, RFC 2386 [5] characterizes QoS 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-to-end users/applications in terms of delay, jitter, available bandwidth, and packet loss. These two QoS perspectives can be demonstrated via a simple model [4] shown in Fig. 1. 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.

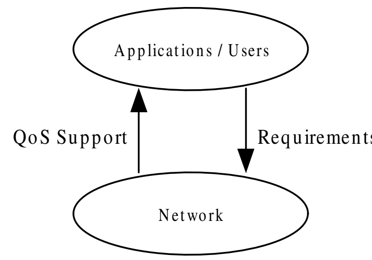

Fig. 1. A simple QoS model

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 in the literature 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.

The remainder of this paper is organized as follows. In Section II, we discuss the QoS support in traditional data networks while Section III analyzes the QoS requirements from the envisioned applications of WSNs. We present the challenges for QoS support in WSNs in Section IV, and a brief review of current research efforts is described in Section V. Section VI outlines some open issues and we end our paper with a summary in Section VII.

II. QoS SUPPORT IN TRADITIONAL DATA NETWORKS

Supporting QoS in wired networks can generally be obtained via the over-provisioning of resources and/or traffic engineering [16][17]. With the method of over-provisioning, we add abundant resources in the network so that it can provide satisfactory services to bandwidth-hungry multimedia applications. This method is easy to realize but all the users are served at the same service class. Therefore, the service may become unpredictable during peak traffic. In the method based on traffic engineering, we classify our users/applications in service classes and assign each class a different priority. In the literature, two approaches based on traffic engineering are exploited to achieve QoS, i. e. , reservation-based and reservation-less approaches. In the reservation-based approach, network resources are assigned according to an application's QoS request and subject to bandwidth management policy. This is employed in Asynchronous Transfer Mode (ATM) and is also the approach of the InterServ model in the Internet. In the reservation-less approach, no reservation is required. QoS is achieved via some strategies such as admission control, policy managers, traffic classes, and queuing mechanisms. Admission control strategy decides if a node can access the network and guarantees that once the node obtains the permission, it will be served with the QoS it is requesting. Policy managers ensure that no node will violate the type of services it is pre-assigned. Traffic classes differentiate the priority of data packets and they thereby achieve a particular per-hop behavior at each intermediate node. Queuing mechanisms are responsible for dropping the packets with lower priority in the case of congestion. This approach is well known as the approach of the DiffServ model in the Internet.

Infrastructure-based wireless networks, such as Wireless Local Area Networks (WLANs) and Broadband Wireless Access Networks (BWANs), are the extension of wired networks, so that the connections can be extended to mobile users. All mobile hosts in a communication cell can reach a base station in one hop. QoS challenges in this context mainly arise from the scarce bandwidth and the complexity of user mobility during the last wireless hop. Thus, it is intuitive for us to integrate the QoS architecture deployed in wired networks with wireless MAC protocols. Wireless MAC protocols may provide data traffic of differentiated classes with corresponding access priorities over the shared wireless medium so that the overall QoS can be supported.

Wireless ad hoc networks can be regarded as an autonomous system or a multi-hop wireless extension to the Internet. As an autonomous system, it has individual routing protocols, while as a multi-hop wireless extension to the Internet, it is required to provide a seamless access to the Internet. Unfortunately, QoS mechanisms used to support QoS in wired data networks cannot be directly applied to ad hoc networks because of the bandwidth constraint and dynamic network topology [15]. In this context, we are required to implement complex QoS functionality with limited available resources in a highly dynamic environment. In the literature, QoS Support in ad hoc networks includes QoS model, QoS resource reservation signaling, QoS routing, and QoS Medium Access Control (MAC). A QoS model specifies an architecture and impacts the functionality of other QoS components. For instance, if the network is only required to provide differentiated services, signaling for every flow state is unnecessary. QoS signaling, the functionality of which is determined by the QoS model, acts as a control center in the QoS support system. It coordinates the behavior of QoS routing, QoS MAC, and other components. The QoS routing process searches for a path with enough resources but does not reserve resources, which enhances the chance that resources can be assured when QoS signaling needs to reserve resources. Without QoS routing, QoS signaling can still work but the process of resource reservation may fail. All upper-layer QoS components are dependent on and coordinate with the underlying QoS MAC protocol. A review of these techniques in detail is available in [15][16][18].

Based on the above discussion, we can draw the following conclusion about QoS support in traditional data networks. They have common QoS requirements, which come from bandwidth-hungry multimedia applications. The same end-to-end QoS parameters are exploited to evaluate the QoS mechanisms in these networks. The research models, such as Interserv, Diffserv or mixed models, do not experience much change. However, the specific techniques to realize QoS support are diverse because of the unique properties of underlying networks. 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.

III. QoS REQUIREMENTS IN WSNs

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, i. e. , temperature, pressure, humidity, noise, lighting condition etc. , 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.

However, since our focus here lies in QoS requirements imposed by the applications on the network, we can initially separate QoS requirements using other perspectives from the networking perspective. As we demonstrated in Section I, different communities may interpret QoS of WSNs in different ways. For example, in applications involving event detection and target tracking, the failure to detect or extracting wrong or incorrect information regarding a physical event may arise from many reasons. It may be due to the deployment and network management, i. e. , the location where the event occurs may not be covered by any active sensors. Intuitively, we can define coverage or the number of active sensors as parameters to measure the QoS in WSNs. In addition, the above failure may be caused by the limited functionality of sensors, e. g. , inadequate observation accuracy or the low reporting rate of sensors. We can thereby define observation accuracy or measurement errors as parameters to measure QoS. Further, it may be induced by information loss during the delivery. We can also define some information transportation related parameters to measure QoS. However, our separation of QoS perspectives is not absolute since a common application requirement such as the performance measure associated with event detection may involve all of them. Our purpose here is to focus on how the underlying network can provide the QoS to applications, in terms of which parameters we can map application requirements into the network infrastructure and measure the QoS support accordingly. For this purpose we describe two perspectives of QoS in WSNs:

A. Application-specific QoS

From this perspective, we may consider QoS parameters such as coverage [19], exposure [20], measurement errors, and optimum number of active sensors [12]. In brief, the applications impose specific requirements on the deployment of sensors, the number of active sensors, the measurement precision of sensors and so on, which are directly related to the quality of applications.

B. Network 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. Generally, there are three basic data delivery models, i. e. , event-driven, query-driven, and continuous delivery models [25]. Before presenting the application requirements, we would like to provide some factors that characterize them as follows:

- End-to-end: The application may require end-to-end or non-end-to-end performance
- Interactivity: The application may be interactive or non-interactive
- Characteristics: The application may or may not be delay tolerant
- Criticality: The application may or may not be mission-critical

1) Event-driven: Most event-driven applications in WSNs are interactive, delay intolerant (real-time), mission critical, and non-end-to-end applications. It means that the events sensors are expected to observe are very important to the success of the application. The application needs to detect these events and accordingly takes an appropriate action as quickly as possible and as reliably as possible. Further, several important points should be mentioned. First, the application itself is not end-to-end, i. e. , one end of the application is the sink, the other end is not a single sensor node, but a group of sensor nodes within the area that is influenced by the event. Second, the data flows from these sensors are likely to be highly correlated and thereby containing much redundancy. Third, the data traffic generated by a single sensor may be of very low intensity. However, very bursty traffic may be generated by a set of sensors due to a common event or a phenomenon known as event showers. Finally, actions in response to the detected event may need to be distributed to sensors or actuators as quickly as possible and as reliably as possible. These sensors and actuators may not be the same set of sensors that notified the sink about this event. This data delivery model involves many typical WSN applications that require event detection and signal estimation/tracking, e. g., sensing of and response to an emergency due to chemical release in a building.

2) Query-driven: Most query-driven applications in WSNs are interactive, query-specific delay tolerant, mission critical, and non-end-to-end applications. To save energy, queries can be sent on demand. This data delivery model is similar to the event-driven model except that the data is pulled by the sink while the data is pushed to the sink in the event driven model. The applications still need to receive these desired data as quickly as possible and as reliably as possible. The important points mentioned for event-driven delivery are also relevant for query-driven delivery.

Note that a query may also be used to manage and reconfigure the sensor nodes. For example, if the sink wants to upgrade the software on the sensor nodes, reconfigure the sending rate, or change the sensor mission, the sink can send out a command to execute these changes. It should be noted that the commands from the sink constitute one-way traffic and require high reliability.

3) Continuous: In the continuous model, sensors send their data continuously to the sink at a pre-specified rate.

- Real-time voice, image, or video data: Real-time data is delay-constrained and has a certain bandwidth requirement. Packet losses can be tolerated to a certain extent. As such, they are not end-to-end applications.
- Non-real-time data: The sink may want to collect periodic data from the sensor field. In this context, delay and

TABLE I
APPLICATION REQUIREMENTS

Class	Event-driven	Query-driven	Continuous
End-to-End	No	No	No
Interactivity	Yes	Yes	No
Delay tolerance	No	Query-specific	Yes
Criticality	Yes	Yes	Yes

packet losses are both tolerated.

4) Hybrid models: In many applications, the data delivery models described above may coexist in the network. Thus, it may require a mechanism to accommodate different types of QoS-constrained traffic.

These requirements are summarized in Table I, and more importantly, we note that there are some differences in application requirements between WSNs and traditional networks. First of all, applications in WSNs are no longer end-to-end applications. Second, bandwidth is not the main concern for a single sensor node. However, bandwidth may be an important concern for a group of sensors for certain time periods due to the bursty nature of sensor traffic. Third, packet losses in traffic generated by one single sensor node can be tolerated to a certain extent since there always exists much redundancy in the data. Finally, most applications in WSNs are mission-critical, which reflects the importance of applications.

As a result, we are convinced that it is insufficient for end-to-end network QoS parameters to measure the QoS support in WSNs. We thereby need to propose some new non-end-to-end QoS parameters. As a whole, we term such non-end-to-end parameters collective QoS parameters. These are

- Collective latency
- Collective packet loss
- Collective bandwidth
- Information throughput

In this paper, we do not propose a collective parameter to characterize jitter since multimedia applications are not major applications of WSNs. Besides, we do not provide a precise definition of each collective QoS parameter. Instead, we utilize an example to demonstrate the novel concept of collective QoS parameters. For instance, in an event-driven wireless sensor network as shown in Fig. 2, the sensors residing within a certain radius of the event are reporting the information about this event to the sink. In this context, collective latency is defined as the difference between the time at which the first packet related to this event is generated by the source sensors and the time at which the last packet related to this event or the last packet used to make a decision arrives at the sink. Collective packet loss is defined as the number of packets related to this event lost during information delivery. Collective bandwidth is defined as the bandwidth that the reporting of the event requires. To sum up, the sink should be concerned about an end-to-end event, instead of the packets from individual sensors. In addition, we should consider information throughput at the sink from a set of correlated sensors instead of an end-to-end data throughput for individual sensors.

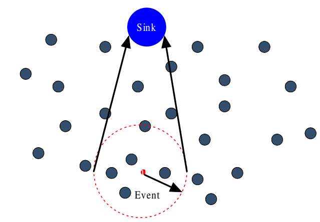

Fig. 2. A typical event-driven wireless sensor network

IV. CHALLENGES FOR QOS SUPPORT IN WSNS

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.

1) 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: simplicity. Computation intensive algorithms, expensive signaling protocols, or overwhelming network states maintained at sensors are not feasible.

2) 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.

3) 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.

4) 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.

5) 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.

6) 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.

7) Multiple sinks: There may exist multiple sink nodes, which impose different requirements on the network. For instance, one sink may ask sensor nodes located in the northeast of the sensor field to send a temperature report every one minute, while another sink node may only be interested in an exceptionally high temperature event in the southwest area. WSNs should be able to support different QoS levels associated with different sinks.

8) Multiple traffic types: Inclusion of heterogeneous sets of sensors raises challenges for QoS support. For instance, some applications may require a diverse mixture of sensors for monitoring temperature, pressure, and humidity, thereby introducing different reading rates at these sensors. Such a heterogeneous environment makes QoS support more challenging.

9) Packet criticality: The content of data or high-level description reflects the criticality of the real physical phenomena and is thereby of different criticality or priority with respect to the quality of the applications [21]. QoS mechanisms may be required to differentiate packet importance and set up a priority structure.

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

V. A SURVEY OF CURRENT RESEARCH EFFORTS ON QOS FOR WSNS

The existing research efforts related to the QoS in WSNs fall into three categories: traditional end-to-end QoS, reliability assurance, and application-specific QoS. A brief review is provided in the following.

A. Traditional end-to-end QoS

Sequential Assignment Routing (SAR) [6] is the first protocol for WSNs that includes a notion of QoS. Assuming multiple paths 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 for purposes of performance evaluation. The objective of the SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network.

A QoS routing protocol (SPEED) that provides soft real-time end-to-end guarantee is demonstrated in [14]. The protocol requires each node to maintain information about its neighbors and exploits geographic forwarding to find the paths. In addition, SPEED strives to ensure a certain speed for each packet delivery 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 delivery before making the admission decision [7].

More recently, another QoS-aware protocol is proposed for WSNs in [8]. Real-time traffic is generated by imaging or video sensors. The proposed protocol finds a least cost and energy efficient path that meets certain end-to-end delay requirement during the connection. In addition, a class-based queueing model is employed to support both best effort and real-time traffic simultaneously.

However, we note that, the solutions described above are based on the concept of end-to-end applications, which may not be necessarily used in WSNs. Next, the mechanisms in each protocol are too complex and costly for resource-constrained sensors. Finally, how to support the QoS in novel data-centric routing protocols should be more interesting since it is much more feasible for them to be implemented in WSNs.

It is also noted that there are some research results available about MAC protocols [9][10][11], but most of them are concerned with energy consumption. A few of them are also concerned with the real-time traffic. However, they do not really support the QoS in WSNs.

B. Reliability assurance

Some end-to-end reliability issues in WSNs are solved in [21][22][23]. The novelty of their work is that they consider the need for information-awareness and adaptability to channel errors along with differentiated allocation of network resources based on the criticality of data. Based on the criticality of data inside a packet, different priority levels are assigned. Each priority level maps to a desired reliability for data delivery. As we emphasized earlier in this paper, the concept of their reliability is still based on end-to-end service. Besides, QoS concerns in WSNs should not be reduced to a single issue of reliability. Other factors such as latency, energy, and bandwidth should also be taken into account.

Y. Sankarasubramaniam *et al.* in [24] propose a new reliable transport scheme (ESRT) for WSNs. ESRT is a novel transport solution developed to achieve reliable event detection in WSN with minimum energy expenditure. More importantly, their solution is based on a non-end-to-end concept. The solution includes a congestion control component that serves the dual purpose of achieving reliability and conserving energy, and the reliability of event detection is controlled by the sink which has more power than sensors. It is worth noting that this paper brings up the concept of non-end-to-end service. However, their solution only resides in an individual transport layer. Further, it does not consider other important QoS factors.

C. Application-specific QoS

QoS has been defined as the optimum number of sensors that should be sending information at any given time in [12]. They utilize the base station to communicate QoS information to each of the sensors using a broadcast channel and exploit the mathematical paradigm of the Gur Game to dynamically adjust to the optimum number of sensors.

In [13], M. Perillo *et al.* provide application QoS through the joint optimization of sensor scheduling and data routing, which can also extend the lifetime of a network considerably compared to approaches that do not use intelligent scheduling, even when combined with power-aware routing algorithms. Actually, their goal is to balance the application reliability with efficient energy consumption. QoS in this paper is described as the application reliability only.

In other papers such as [19][20], QoS is also defined as coverage or exposure, the basic idea is how to cover the desired area of interest or leave no sensing holes so that sensors can detect unexpected events as quickly as possible and as reliably as possible. The deployment of sensors can be pre-defined or random.

As described in Section III, none of these definitions is from the network perspective. Thus, the QoS support in their methods is not directly related to the QoS support from the underlying network.

VI. Open research issues

As we know, QoS-enabled traditional networks attempt to ensure:

- That applications/users have their QoS requirements satisfied, while ensuring an efficient resource usage, i. e. , efficient bandwidth utilization.
- That the most important traffic still has its QoS requirements satisfied during network overload.

In the context of WSNs, efficient resource usage not only means efficient bandwidth utilization, but also a minimal usage of energy. Thus, QoS support in WSNs should also include QoS control mechanisms besides QoS assurance mechanisms employed in traditional networks, which can eliminate unnecessary energy consumption in data delivery. Further, besides during network overload, the most important traffic should still have its QoS requirements satisfied in the presence of different types of network dynamics, which may arise from node failure, wireless link failure, node mobility, and node state transition. We have listed the main technical challenges in Section IV. Based on these challenges and our goals, the following are identified as open research issues in QoS support in WSNs.

1) Simpler QoS models: Diffserv and Interserv models may be not applicable in WSNs due to their complexity. Novel and simple QoS models are required to identify the architecture for QoS support in WSNs. Cross layer instead of traditional layered design may be helpful to work out a simpler model.

2) QoS-aware data dissemination protocols: It is very interesting to analyze how these protocols such as directed diffusion support QoS-constrained traffic while minimizing energy consumption. Do these protocols support priority? Can the network send high-priority traffic even with overloaded traffic situation or under a highly dynamic network?

3) Services: What kind of non-end-to-end services can WSNs provide? Are traditional best effort, guaranteed, and differentiated services still feasible in this new paradigm?

4) QoS support based on collective QoS parameters: It is very interesting to explore the support mechanisms for three classes of data delivery models using collective QoS parameters. Further, how do the mechanisms differ from those in traditional networks?

5) Traditional end-to-end energy-aware QoS support: Although these are not of main concern in WSNs, they may be applied in some scenarios. Also, it is very interesting to explore the limit on QoS assurance in an extremely resource-constrained network.

6) Trade-offs: Data redundancy in WSNs can be intrinsically exploited to improve information reliability. However, it spends too much energy to transmit these redundant data. If we introduce data fusion, it can reduce data redundancy in order to save energy, but it also introduces much delay into the network. What is an optimum trade-off among them? This optimum trade-off may be achieved analytically or by network simulations.

7) Adaptive QoS assurance algorithms: It is desirable to maintain QoS throughout the network life instead of having a gradual decay of quality as time progresses. This prevents gaps in data sets received by the sink. These gaps, that directly affect QoS, are caused by network dynamics. As a result, some adaptive QoS algorithms may be required to defend against network dynamics.

8) Service differentiation: What is the criteria of differentiation? Should it be based on traffic types, data delivery models, sensor types, application types, or the content of packets? Considering the memory and processing capability limitations, we cannot afford to maintain too many flow states in a node. Thus, it is desirable to control network resource allocation to a few differentiated traffic classes such that a desired maximum resource utilization is obtained.

9) QoS support via a middleware layer: If QoS requirements from an application are not feasible in the network, the middleware may negotiate a new quality of service with both the application and the network. Such a middleware layer, which may be used to translate and control QoS between the applications and the networks, is of great interest.

10) QoS control mechanisms: Sensors may send excessive data sometimes and thereby waste precious energy while they may also send inadequate data at other times so that the quality of the application cannot be met. Some novel centralized or distributed QoS control algorithms are desired.

11) The integration of QoS support: The mechanisms of QoS support in WSNs may be very different from that in traditional networks. However, since the requests to WSNs can be from a user/application through a traditional network such as the Internet, further research is necessary for handling the differences between them and maintain the QoS services seamless to the application running over both networks.

VII. Concluding Remarks

Few efforts have been made in the research field of QoS support in WSNs so far. In this survey paper, we analyzed the QoS requirements imposed by the main applications of WSNs, and we claim that the end-to-end QoS concept used in traditional networks may not be sufficient in WSNs. Some non-end-to-end collective QoS parameters are envisioned due to this significant change. Further, we list many challenges posed by the unique characteristics of WSNs and report on the state of the art in terms of a few current research efforts in this field. Finally, we are convinced that the QoS support in WSNs should also include QoS control besides QoS assurance mechanisms, and some exciting open issues are identified in order to stimulate more creative research in the future.

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