

Qos Management for Large Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSN) is a key area of new investments and investigations. It promises a new domain on the way computers and humans interact with our environment. It serves a large number of applications that can be very critical to the extent of saving human life. Therefore, serving reliable and timely information is a key demand to any WSN. Quality of Service (QoS) in WSN discusses some techniques and requirements to provide such reliable and trusted service. In this survey we will trace the efforts to develop QoS -enabled models unique characteristics such as severe resource constrains ending by a review of QoS Management for Large WSN.

Keywords: Quality of service, Wireless sensor network.

Introduction

Computer networks transport simultaneously several flows, fact that makes necessary a multiplexing mechanism. Transport procedures affect the traffic flows, reason for which the traffic has to be characterized and quality of service (QoS) requirements need to be established. Traffic types and their QoS requirements impose the implementation of QoS methods and architectures.

Several definitions for Quality of Services (QoS) have been identified throughout the years in different standards and bibliographical references, without any unique and exhaustive formal definition. The most illustrative definitions of the concept are: [ISO 8402/1986] states that quality is the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs. The product, respectively the service, represents the result of the activities or processes within the system; [ITU-T, 1994] defines the collective effect of services' performance, which determines the level of satisfaction of the service user; [ISO/IEC X641] defines the qualities that refer to the way an object or a group of objects (components)

collectively works, or reflect the qualitative performance of the service offered through the network.

At network level, QoS represents the network capability to deliver better services for the selected flows over different technologies. The main goal of QoS is to provide priority including dedicated bandwidth, controlled latency and jitter, and improved loss characteristics, which represent the main QoS parameters.

The concept of QoS for large networks has emerged with the developing of new services, such as VoIP or multimedia applications that requires bandwidth availability, controlled latency and jitter and improved loss characteristics. Best-effort networks no longer meet their QoS requirements. Also Internet Service Providers and their clients require means for rating and pricing the quality of the offered/received services. Also, for multimedia applications such as video or audio streaming, end-to-end QoS guarantees are highly desirable in order to ensure user satisfaction.

Different research projects point out that the issue of provisioning end-to-end QoS in the Internet is currently being investigated by both research and standardization communities.

Quality of Service (QoS) aims at providing better networking services over current technologies such as ATM, Ethernet and others. The Internet uses the *best-effort* model; as it provides no guarantees on when packets will be delivered? And it does not differentiate between network streams. The main three parameters for QoS are latency (delay), jitter and loss. Delay is the total amount of time a network spends to deliver a frame of data from source to destination. Jitter in turn is the delay between two consecutive packets in that frame. While loss determines the maximum amount of packets loss the stream can tolerate to provide good quality. Each parameter has been investigated thoroughly and many solutions are proposed such as forward error correction and interleaving [1]. Other QoS parameters include reliability, network availability and bandwidth.

Wireless Sensor Networks (WSN) are composed of many tiny, low-cost, low-power and scattered devices called sensor nodes. Each node integrates a processor, memory, and transceiver and power source in one small device that has the ability to observe, process and send data about observed phenomenon to its neighboring nodes destined to a central processing unit sometimes referred to as a sink. A sensor node should have the ability to process as much information locally as possible instead of just disseminating raw data to save energy, because radio frequency (RF) communication is the key energy consumer [2]. Usually the main source of energy in a

sensor node is a battery; so the life time for any node depends on the life of the battery itself. For these reasons many Media Access Control (MAC) protocols have been proposed to bring radio communication on and off periodically instead of just listening to the channel all the time e.g. SMAC [3]. Energy conservation is one of the main obstacles to any proposed protocol in sensor networks, while maintaining high QoS measurements is the main goal in traditional networks [4]

Quality of Services in Wireless Sensor Networks:

Regular wired networks mainly send data between nodes without the knowledge of the nature of the carried data (*data transparency*), they mainly uses end-to-end communication model therefore parameters like delay, bandwidth, jitter and loss can provide acceptable QoS if managed properly. While in WSN, these parameters are not fully applicable, because sensor nodes mostly communicate using non-end-to-end model; each node communicate only with its neighboring nodes; that's mean no connection need to be established between source and destination at the beginning of transmitting process.

Another problem arise from the fact that intermediate sensor nodes has the ability to generate data as well beside routing, along with the most challenging problem which is energy, all these factors arise new QoS parameters like coverage, exposure, energy cost and network life time. The problem of coverage could happen when no sensor could observe and inform the sink about an event. This may happen because of noisy channels, deployment location or network management [18]. Exposure is related to coverage that provides measures of how an object can be observed by a sensor over a period of time. Energy cost defines the process of finding the best route to destination according to energy conservation. While network life time is the total time of WSN until it is not able to satisfy user's needs. Implementing the two QoS models of Internet on WSN would not be practical. IntServ mainly depends on reserving the bandwidth between source and destination while saving state information on each intermediate node. This can be impractical in ESN for three main reasons: the complexity to achieve such service, second; limited memory capability in each sensor node that can't save per-flow state information and last because the route usually is not known between source and destination at the beginning of transmission process. DiffServ faces another problem beside complexity, that the core ideas behind DiffServ is queuing and prioritizing packets based on service priority level. Queuing requires large memory which normally sensor node doesn't have. Reliability, as a measure of QoS, have the ability to detect and repair packet loses in WSN, as well it should provide reliable method for transporting data from sink to node and vice versa; therefore, reliability protocols

categorizes into two groups: Event-to-Sink and Sink-to-Event. Event-to-Sink transport usually carries information about observed phenomena; in most cases it might be very critical data needs to be reliably communicated to the sink. Several protocols has been proposed such as Reliable Multi-Segment Transport (RMST) [19] and Event-to-Sink Reliable Transport (ESRT) [20]. Sink-to-Sensor usually carries queries or update control information. A protocol such as Pump Slowly Fetch Quickly (PSFQ) [21] is proposed for reliable transfer of tasks and reprogramming the WSN nodes.

What Makes QOS in Large WSN Different?

The unique characteristics of Large WSN such as small size of sensor nodes, had forced us to equip it with limited batteries, processor and transceiver that lead to restricted power source, slower processing capabilities and constrained communication power. These limitations have advanced new challenges that are discussed briefly as follow:

Power: This considers the most critical limitation. Therefore, almost every protocols proposed consider the energy problem. The main power consumer as discussed earlier is communications; so a high compression and local data processing should be done on each node before dissemination. Achieving a better service (QoS) is always the price of energy [22].

Bandwidth: As discussed in section one that bandwidth is one of QoS parameters; so the lack of bandwidth presents more difficulties in achieving QoS in WSN Using data compression and utilizing different bandwidth capabilities based on nature of stream are two proposals to overcome the scarce of bandwidth

Memory size: The limitation of memory (cache) size is affecting most proposals to enhance WSN networking capabilities. In some cases local memory is not enough to load the whole operating system in addition to implement extra QoS measures

Standardization: The lack of standardization in WSN makes it hard to implement a QoS solution. *OR There are no standardizations yet in most WSN layers of functionality to be able to build a QoS based on them.* ZigBee may consider a first attempt.

Lifetime: The nature of WSN life is limited because of the fact that most nodes operate on unchargeable power source like battery, another reason is the ease of node damage. Attempts to recharge the battery using solar or wind power has been proposed.

Density: Leads to data redundancy, although it may help to achieve reliability but it may add overhead and consume power to aggregate traffic to sink, as well it may add some sort of latency and complexity to QoS design. [14]

Application diversity: WSN consider being application specific rather than general purpose, they carry only hardware and software actually needed for the application. The vast number of applications in WSN offers different QoS requirements.

QoS Metrics

In [5] QoS metrics (bandwidth, delay, jitter, cost, loss probability) are categorized in three types of metrics:

- additive (delay, jitter, cost and hop-count),
- multiplicative (reliability),
- concave (bandwidth).

Metrics for QoS routing protocols in MANET as described in [5]

- Minimum Throughput (bps) – the desired application data throughput.
- Maximum Delay (s) – maximum tolerable end-to-end delay for data packets
- Maximum Delay jitter – difference between the upper bound on end-to-end delay and the absolute minimum delay
- Maximum Packet loss ratio - the acceptable percentage of total packets sent, which are not received by the final destination node.

QOS challenges in large WSN

Several QoS improvement techniques have been proposed over the years for enhancing the capabilities of different types of wireless networks.

The problematic of end-to-end QoS support in Mobile Ad-hoc Networks (MANET) and Wireless Sensor Networks (WSN) has been researched both by academia and industry.

A mobile ad hoc network (MANET) consists of mobile nodes that can communicate with each other through wireless links without an existence of fixed infrastructure, thus allowing users to set up the network fast and cost effective. For these characteristics, MANETs have been widely used in various application areas. [5]

In [6] the primary challenges in MANET are presented:

- Unicast routing
- Multicast routing
- Dynamic network topology
- Speed
- Frequency of updates or Network overhead
- Scalability

- Mobile agent based routing
- Quality of Service
- Energy efficient/Power aware routing
- Secure routing

Routing protocols can be classified into two categories:

- Table Driven Protocols - Proactive Protocols
- On-Demand Protocols - Reactive Protocols

In Table Driven routing protocols each node maintains one or more tables containing routing information to every other node in the network. Some of the proactive protocols are: DSDV [7], or GSR [8]

In On-Demand routing protocols routes are created when needed. Some of the representative reactive protocols are DSR [9], AODV [10] or TORA [11].

Research on QoS in MANETs includes QoS routing, QoS resource reservation, QoS benchmarking.

In [5] it is stated that provision of quality of service (QoS) guarantees is much more challenging mainly due to node mobility and resource constraints. The responsiveness of the routing protocols in MANETs is of high importance due to the problem of node mobility [12].

Some of the widely used QoS frameworks for MANET are: INSIGNIA, SWAN, and DACME. INSIGNIA framework is an in-band (control information is carried along with data in IP packets) signaling system for supporting quality of service (QoS) in mobile ad hoc networks. INSIGNIA is designed to support the delivery of adaptive real-time services and includes fast session/flow/microflow reservation, restoration and adaptation algorithms between source/destination pairs [13]

The SWAN model [14] is a stateless network model which uses distributed control algorithms to deliver service differentiation in mobile wireless ad hoc networks. The authors showed that an important benefit of SWAN is that it is independent of the underlying MAC layer, and can be potentially suited to a class of physical/data link wireless standards

The DACME (Distributed Admission Control for Manet Environments) solution [15], offers a new framework for QoS support in MANETs based on the IEEE 802.11e technology. DACME is offering a distributed admission control mechanism for real-life MANETs and support multipath routing protocols and adaptive multimedia applications.

In [16], QoS routing protocols are classified as:

-treatment of network topology (flat, hierarchical or location-aware),
-approach to route discovery (proactive, reactive, hybrid, or predictive). In [5] a taxonomy of QoS routing protocol is presented:

In [4] the authors highlights that QoS routing usually involves two tasks: collecting and maintaining up-to-date state information about the network and finding feasible paths for a connection based on its QoS requirements. Also, the major problems to provide QoS guarantees are:

- Unreliable channel,
- Maintenance of route
- Mobility of the node
- Limited power supply
- Lack of centralized control
- Channel contention
- Security

WSN Communication Protocols

Wireless Sensor Networks like any other network architecture share almost all OSI layers, but with slightly differences we will try to put our hand on some of them in respect to QoS, starting from the top (application layer) down to the physical layer.

Application Layer

QoS may interpret in two different prospective [18]. One prospective defines QoS as quality perceived by the user or application. The other view is defining QoS in respect to network, as how the network is able to provide QoS to users or applications. We can redefine the first type as set of rules or parameters a user or application is setting to get desired service from the network. For example the user can ask the network to send their data in pair; to achieve higher reliability. In user/application perspective many parameters can be defined by user to achieve some QoS in *WSN*:

Fidelity: A user can instruct the network to send their queries back to sink in pairs, or do not accept any event that have been seen by n number of nodes only.

Update (Freshness): Sensors should send queries to sink every n time, even there are no events.

Mode: User/Application defines how sink will interact to events. In general four data delivery models are defined: events-driven, query-driven, continuous and hybrid [23].

In network perspective, providing QoS to application or user define new QoS parameters:

Query processing: Is the ability of WSN to perform in-network processing instead of sending raw data to sink. For example a sink may send a query “What is the highest temperature in the forest?”, in response to this query each sensor will send back the temperature to the sink who is in turn will calculate the highest temperature, or let nodes in the network find it out themselves and then send the result only. This can be accomplished with the help of aggregation mechanisms.

A Tiny AGgregation Service (TAG)[24] is one approach to combine related data send by nodes into one compact record based on set of aggregation values specified by queries

Coverage: High coverage is a key to robust sensor network and it considers one of QoS measures [25]. It discusses the ability to provide the largest area of coverage possible using the lowest number of sensor nodes. Generally nodes are deployed either randomly or based on predefined location. Random deployment usually suffers from lack of coverage; this can be solved by allocating some extra nodes manually during network runtime. Having good coverage algorithms can save power and improve sensor network connectivity. In an area that are covered by multiple sensors we can turn some sensors off (save power) or instruct one or two sensors only to sense environment (less redundant data). k-UC and k-NC are some algorithms proposed to determine how adequately each sensing area is well covered [26]. A related problem to coverage is *exposure* that measures the ability of a given network to observe an object over a period of time [27].

RTP (multimedia streaming over WSN): Real-time Transport Protocol (RTP) defined in the IETF RFC 3550 [28] provides end-to-end delivery service for real-time audio or video. RTP is a packet based communication protocol that adds timing and sequence information to each packet to allow the reassembly of packets to reproduce real-time audio or video.

A Real-time Control Protocol (RTCP) is responsible to maintain, control and diagnosis RTP sessions. In addition both sender and receiver have to send reports to each other to synchronize packet's delivery.

Implementing RTP as is in WSN can suffer from some problems. First, it requires high caching capabilities to save state information. Second, WSN are scarce in term of bandwidth. Third, Scalability can be another problem as WSN may consists of hundreds of nodes. Besides sending “high quality” audio or video streams are usually not required. However, some modifications are

essential to RTP before implementing it on WSN; for example, forcing one RTP streaming session at a time, and negating receiver reports.

Transport Layer

Generally transport layer provides two main services:

1. Reliable data delivery service.
2. Flow and congestion control mechanisms.

Normal transport protocols developed for wired or wireless communication does not address WSN resource constrains. In addition, they are implemented with address-centric and end-to-end data delivery notion in mind. Therefore, developing transport protocols specific for WSN should take the following points into consideration [4]:

Reliability for both ways of communications; sink-to-sensors and sensor-to- sink.

A good Congestion Control mechanisms increases network efficiency and save power. •Self-configuration approaches to adapt to frequent changes in network topology. •Should be energy-aware.

Data-centric.

Reliability of data delivery is our main concern. Traffic in WSN is either from sensor to sink (sensed information) or from sink to sensor (control/update information). Each of these traffics is described in the following subsections in addition to reliable multicast.

Sensor-to-sink

Generating trusted data is the main goal of any WSN. Therefore, the need for reliable transport protocols is crucial. Some refer to this process as event-to-sink because it does not matter which sensor has generated the information we care most about the information itself. Thus it called data-centric model of delivery. As an example, two reliable transport protocols are presented.

Event-to-Sink Reliable Transport (ESRT) [20]: is a novel transport protocol provide reliability and congestion control that can conserve power as well. The protocol has the ability to collect (aggregate) information provided by many sensors, thus it does not require individual ID for each node. While it works mainly on the sink it requires minimum functionalities at sensor node to conserve resources. There is no delivery guarantees for individual packets and it's a single hop only by employing a powerful sink.

Reliable Multi-Segment Transport (RMST) [19]: Build on Direct Diffusion [29] it takes advantage of diffusion mechanisms for routing, path recovery and repairs. It provides guaranteed

delivery of all fragments (not necessary in order) and it considers 3 layers: Application, Transport and MAC layers. It uses in-network caching to provide reliability; therefore, it may bring overhead to sensor network.

Sink-to-Sensor

Data sent from sink to sensor are mainly queries, updates or operational instructions. It may include firmware or OS update. These need to be transferred reliably to sensors. Mostly, Sink-to-Sensor suffers less congestion than opposite path; therefore, we may implement a less aggressive congestion control mechanisms [8]. As an example, PSFQ is discussed below.

Pump Slow, Fetch Quickly (PSFQ) [21]: It distribute data slowly (Pump Slow) while recover quickly from error or loss (Fetch Quickly) by using data caching to guarantee ordered delivery. It ensures reliability by a stop and waits NACK based approach. And operate correctly in poor link quality environment. It uses several timers and data caching extensively.

Table-1: Summarizes all 3 transport protocols discussed earlier [30].

Protocol Characteristics	ESRT	RMST	PSFQ
Quick Summary of Protocol Operations	Sink controls event reporting frequency.	Send packet, insert packet sent to cache, wait for NACK to retransmit.	Pump, Fetch and Report
Guaranteed/Stochastic reliability	Stochastic	Stochastic	Guaranteed

Table-2: Characteristics of data transport reliability protocols

Type of reliability	End to End	Hop by Hop	Hop by Hop
Direction of Information flow	Sensor to Sink	Sensor to Sink	Sensor to Sink
Implementation layer	Transport Layer	MAC, transport and Application layers	Transport Layer
Underlying routing protocol	Any	Direct Diffusion	Any
Type of acknowledgment	None	NACKs	NACKs
Use of in-network caching	No	Yes	Yes
Packet delivery order	Out of order	In order	In order
Assumption made	Sink node is not energy-constrained and transmit directly to all sensors.	Direct diffusion is in place	For applications that require very high reliability like node re-tasking
Congestion Control mechanism	Sink measures congestion and sets packet generation rate for all sensors	Retransmission possible through intermediate nodes' cache reducing NACK implosion	In-sequence forwarding reduces unnecessary retransmissions
Computational overhead	Best score mode – Receiver has to compute which node to ask for retransmission based on link quality and importance of the nodes. Accuracy Guarantee mode – Binomial tree has to be build to find out the list of nodes to ask for retransmission.	Sending of explicit NACKs to request for missing packets	Many timers
Packet overhead	NACKs	NACKs. Implosion of NACKs possible	Proactive and aggressive NACKs
Energy consumption overhead	High on the receiver nodes due to intensive computation	Transmission of redundant data	Transmission of high number of NACKs

Reliable Multicast

Multicasting is the process of sending a message to select multiple recipients who have joined the appropriate multicast group. The sender has to generate only one data stream, a multicast-aware router will forward a multicast to a particular network only. SRM, RMTP and PGM are some reliable multicast protocols designed for the Internet.

Reliable Multicast in WSN is not well investigated. To the best of our knowledge no research has dealt with this issue so far. Multicast of information usually happens in reverse- path (Sink-to-Sensor) where usually we have one sender and multiple receivers. Some work has been done in Mobile Ad-hoc Network (MANET) such as ReACT and M-LANMAR; however, no approach discusses the unique requirements of WSN. PSFQ has some similar properties to Scalable Reliable Multicast (SRM) but does not consider a reliable multicast protocol.

Network Layer:

Network layer mainly deal with determining the route from source to destination and manage traffic problems. Generally, network layer is responsible for end-to-end packet delivery, whereas the data link layer is responsible for node-to-node (hop-by-hop) packet delivery. Routing protocols in WSN can be categorized as [3]:

1. Data-Centric: Data are disseminated between sensors without the need for global unique ID. It depends on the naming of desired data.
2. Hierarchical: Sensors are controlled by a sensor (cluster-head) to aggregate data. Cluster-head is either a special (more powerful) node or an elected sensor among each cluster.
3. Location-based: These protocols are location-aware; usually by utilizing a GPS. The ability to find the location makes it easier to route data to single and specific region instead of broadcasting traffic to all regions.
4. QoS based: Protocols that ensure some QoS requirements such as minimum cost path; in term of energy for example, low throughput and delay.

Sequential Assignment Routing (SAR) [31]: Works with coordination of other algorithms (SMACS and EAR), together they provide organization and mobility management in sensor network. It enables nodes to discover their (one hop) neighbors and establish transmission/receiving schedule without a central management system. SAR algorithm creates a multiple tree for a group of sensor nodes. The root in that tree is one hop to the sink. While building the tree sensor network tries to avoid nodes that have less QoS and low energy reserve.

SPEED [32]: A real-time communication protocol for WSN that provide soft real-time end-to-end guarantees. It uses location-based mechanisms to find the route to the sink. By employing location awareness; *SPEED* can calculate distance, thus can find out the time it takes to deliver packets to destination prior to admission (end-to end delay). In addition it can handle congestion avoidance. *SPEED* maintains a table for immediate neighbors only, it does not maintain a routing table or per-destination state; therefore, its memory requirements are minimum. It does not have any extra energy-awareness mechanisms other than spreading traffic uniformly through the entire network.

Energy-Aware QoS Routing Protocol [1]: It concerns mainly about power, it finds a least cost and energy efficient path that meets certain end-to-end delay requirement during the connection. Additionally, a class-based queuing model is employed to support both best effort and real-time traffic simultaneously. The link cost used is a function that captures the nodes' energy reserve, transmission energy, error rate and other communication parameters. However, it's based on the concept of end-to-end applications, which may not be necessary used in WSN and it's too complex [14].

Data Link Layer

Data Link layer ensures that data is transferred correctly between adjacent network nodes in a wide area network. The data link layer is divided into two sub layers: The Media Access Control (MAC) layer and the Logical Link Control (LLC) layer. The MAC sub layer controls how a computer on the network gains access to the data and permission to transmit it. The LLC sub layer controls frame synchronization, flow control and error checking.

Media Access Control (MAC):

MAC layer in WSN join together almost all problems from traditional wired and wireless networks in additional to other new challenges such as the lack of unique ID, power constrains and the frequent changes in WSN topology.

Current proposed MAC protocols in WSN concerns mainly about power conserving. They don't support real QoS [14] due to the tradeoffs between energy- efficiency and QoS capability.

Quality-of-service specific Information Retrieval (QUIRE) [33] a MAC protocol optimizes the network performance while ensuring a given QoS requirement. Based on the density of deployment and the QoS specified by the maximum distortion for reconstructing the random field, QUIRE partitions the sensor network into disjoint and equal- sized cells. It eliminates redundant transmissions by ensuring, via carrier sensing; only one sensor in each cell transmits.

It explores the diversity of a fading environment by incorporating channel state information into carrier sensing so that the sensor with the best channel transmits.

Conclusion

Implementations of Quality of Service (QoS) in Large Wireless Sensor Networks (WSN) mainly come from resources constraints beside lack of standardizations. In this survey We analyzed the major work in this field, trying to encompass current research efforts in straightforward approach. We believe, achieving similar QoS performance of traditional network in WSN is achievable by designing a unified framework and using combination of protocols. Another point I want to conclude is that we can use WSN to process a huge amount of data like the Internet if we redesign the whole model or protocol specifically for WSN.

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