Quality of Service in 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 on WSN networks. First, an introduction to QoS in traditional networks stating its parameters and techniques is presented followed by introductory review of WSN and its unique characteristics such as severe resource constrains ending by a review of QoS implementations in protocol layer stack of WSN.

1. Introduction

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 [33]. Other QoS parameters include reliability, network availability and bandwidth.

Providing hard guarantees as in Integrated Services (IntServ) or soft guarantees as in Differentiated Services (DiffServ) are the two main approaches to QoS in the Internet. IntServ [11] establishes a virtual dedicated link between source and destination. The Resource Reservation Protocol (RSVP) signaling protocol responsible for checking the network desired bandwidth and delay requirements. IntServ provides per-flow reservation; therefore, every node needs to maintain state information about every flow. As a result IntServ suffer from a scalability problem. DiffServ [42] offers different level of service classes, it employ Differentiated Services Code Point (DSCP–6 bits) field in the IP's Type of Service (ToS) byte to assign different class to each flow. In turn, each network node treats every flow differently which is known as the per-hop behavior (PHB). Therefore, state information about every flow is not needed along the network path. A third model of QoS in the Internet is known as Adaptive Applications that adapt to network congestion based on QoS feedback by adjusting the streaming speed. Bolot [10] proposes a set of feedback mechanisms for use in adaptation of the output rate of video coders according to the state of the network.

Extending QoS to wireless networks presents new challenges due to radio channel characteristics, mobility management [25], higher loss, battery power constrains and low bandwidth [37]. However, most current QoS protocols can be implemented in wireless local area networks (WLAN) with some modification because the last hop is the only wireless stage in these networks. In wireless networks like Ad hoc wireless networks or the new emerging wireless sensor networks which are totally wireless, a new set of QoS parameters, mechanisms and protocols are needed.

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, 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 [22]. 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 [58]. 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].

Sensor nodes are densely and randomly deployed, this can provide better accuracy and more energy saving since nodes can use short-range communication. However, if not managed properly, data redundancy and collisions may occur. For example, in a forest hundreds of nodes programmed to inform a central sink if the temperature exceeds 45° C, when the event occurs, many nodes may disseminate at once the same information to the sink, resulting in data redundancy and implosion at the sink. To solve this problem while maintaining a degree of reliability, data aggregation techniques combine and summarize the data coming from different sources into one data stream [36].

Routing in sensor networks is different from routing in traditional network, because of the fact that each sensor does not necessarily have a global unique ID. Selecting the next hop node becomes harder. More details about routing found on section 4.3.

Wireless sensor networks inherit almost all challenges from regular Wireless Local Area Network (WLAN) and Mobile Ad hoc Networks (MANET) in addition to the following [22] [4]:

- A sensor node suffers from very limited power source, not like PDAs or laptops which usually are recharged.
- A sensor network topology faces frequent changes due to external forces like animals, tanks or humans; or internal reasons like power or software failure.
- A sensor node does not have a global ID, which makes most of current network protocols inapplicable to WSN.

- Sensor networks mainly operate without any human intervention and they should be Self-configurable.
- Sensor nodes are densely deployed that increase redundancy and collisions.
- Sensors have the ability to know the nature of information they are currying, unlike traditional network where intermediates' nodes only forward packets of data.
- Sensor nodes normally use the broadcast communication model, while traditional networks use point-to-point communication.

For all the above reasons, implementing QoS in Sensor Networks differ from regular QoS implementations in other types of networks. Next is a discussion of Quality of Service in WSN in general followed by some challenges in deploying normal QoS mechanisms in Wireless Sensor Networks.

2. 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 it 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 [14]. 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 vise 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) [52] and Event-to-Sink Reliable Transport (ESRT) [47]. Sink-to-Sensor usually carries queries or update control information. A protocol such as Pump Slowly Fetch Quickly (PSFQ) [54] is proposed for reliable transfer of tasks and reprogramming the WSN nodes. I will discuss each protocol in section 4.

3. What makes QoS in WSN different?

The unique characteristics of WSN such as small size, 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 [59].
- 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.

4. 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.

4.1. Application Layer:

QoS may interpret in two different prospective [14]. 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. I 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 [53].

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) [36] 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 [40]. 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 [29]. A related problem to coverage is *exposure* that measures the ability of a given network to observe an object over a period of time [41].

- **RTP (multimedia streaming over WSN):** Real-time Transport Protocol (RTP) defined in the IETF RFC 3550 [49] 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.

4.2. 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.

4.2.1 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)** [47]**:** 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 recourses. 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)** [52]**:** Build on Direct Diffusion [30] 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.

4.2.2 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)** [54]: 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 wait 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 [13].

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
Type of reliability	End to End	Hop by Hop	Hop by Hop
Direction of information flow	Sensor to Sink	Sensor to Sink	Sink to Sensors
Implementation layer	Transport Layer	MAC, transport and Application layers	Transport layer
Underlying routing protocol	Any	Direct Diffusion	Any
Type pf acknowledgment used	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

Table 1: Characteristics of data transport reliability protocols

4.2.3 Reliable Multicast:

Multicasting is the process of sending a message to selected 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.

4.3 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.

Of course, our concern here is QoS based routing protocols. Only few attempts are made, a recent survey [3] shows only three protocols:

- **Sequential Assignment Routing (SAR)** [50]: 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** [27]: 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 nor 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].

4.4 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 sublayers: The Media Access Control (MAC) layer and the Logical Link Control (LLC) layer. The MAC sublayer controls how a computer on the network gains access to the data and permission to transmit it. The LLC sublayer controls frame synchronization, flow control and error checking.

In this survey, a brief discussion about MAC layer is only presented.

4.4.1 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 trade offs between energy-efficiency and QoS capability.

QUality-of-service specific Information REtrieval (QUIRE) [62] 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.

5. Conclusion:

Implementations of Quality of Service (QoS) in Wireless Sensor Networks (WSN) still in early stages, great efforts need to be invested. Difficulties in WSN mainly come from resources constrains beside lack of standardizations. In this survey I analyzed the major work in this field, trying to encompass current research efforts in straightforward approach. I believe, achieving similar QoS performance of traditional network in WSN is unachievable; there is a continuous trade-off between limited sensor's resources like power, memory or computational capabilities and QoS support. However, we are not expecting to utilize WSN to process a huge amount of data like the Internet. WSN mainly will be used to process less network traffic and deal with fewer numbers of users at any time. Therefore, high support of QoS for all type of network's stream is not required; beside there is no need for high quality video or audio stream in WSN.

Another point I want to conclude my survey with is that most proposed protocols for QoS in WSN, came from the Internet way of thinking! We need to think totally in a new fashion to serve WSN's unique requirement. We can utilize some ideas but need to redesign the whole model or protocol specifically for WSN.

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