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Comparative Analysis of QoS-Aware Routing Protocols for Wireless Sensor Networks

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Abstract

The main ability of wireless sensor networks (WSNs) is communicating and sensing between nodes, which are deployed in a wide area with a large number of nodes. Wireless sensor networks are composed of a large number of sensor nodes with limited energy resources. One critical issue in wireless sensor networks is how to gather sensed information in an energy efficient way, since their energy is limited. The limiting factors of the sensor nodes, such as their finite energy supplies and their moderate processing abilities, as well as the unreliable wireless medium restrict the performance of wireless sensor networks While contemporary best-effort routing approaches address unconstrained traffic, QoS routing is usually performed through resource reservation in a connection-oriented communication in order to meet the QoS requirements for each individual connection. This article surveys a sample of existing QoS-Aware Routing Protocols for Wireless Sensor Networks and highlights their key features, including merits and limitations.

Keywords: Wireless sensor networks, Routing protocols, QoS-Aware Routing Protocols.

1. Introduction

Wireless sensor networks play a key role in sensing, collecting, and disseminating information about environmental phenomena. Sensor networks hold the promise of revolutionizing sensing in a wide range of application domains because of their reliability, accuracy, flexibility, cost-effectiveness, and ease of deployment. (Sameer Tilak., Nael B. Abu-Ghazaleh., Wendi Heinzelman, 2002). One of the major design goals of WSNs is reliable data communication under minimum energy depletion to extend the lifetime of the network. This may be achieved via aggressive energy management techniques. Owing to their poor energy conservation, traditional routing protocols are not suitable for WSN applications. It is highly desirable to employ an energy-efficient route discovery and data relaying techniques to transfer data between the sensor nodes and the base station (BS), the data aggregation point. For increasing network lifetime it is essential to make the most efficient use of every node since each node of WSNs has limited energy resources. The important key point in utilizing a network is to increase the network's performance by constructing an efficient routing protocol (Aries Kusdaryono., & Kyung Oh Lee, 2011).Routing of sensor data has been one of the challenging areas in wireless sensor network research. It usually involves multi-hop communications and has been studied as part of the network layer problems (C. Intanagonwiwat, R. Govindan & D. Estrin, 2000; W. Heinzelman, J. Kulik, & H. Balakrishnan, 1999; Heinzelman, A. Chandrakasan, & H. Balakrishnan, 2000; R. Shah & J. Rabaey, 2002). Moreover, there is a major energy resource constraint for the sensor nodes. As a consequence, many new algorithms have been proposed for the problem of routing data in WSNs.

QoS protocols have several applications including real time target tracking in battle environments, emergent event triggering in monitoring applications etc. Energy-aware QoS routing will ensure guaranteed bandwidth through the duration of connection as well as providing the use of most efficient path (Kemal Akkaya & Mohamed Younis, 2003). This article surveys QoS-Aware Routing Protocols for WSNs. Section 2 classifies routing protocols. Section 3 discusses existing QoS-Aware Routing Protocols for WSNs. Section 4 compares existing QoS-Aware Routing Protocols. Section 5 concludes the article.

2. Routing Protocols for Wireless Sensor Networks

Data gathering and processing are important functions of sensor networks and all data from individual sensor nodes need to be sent to the BS, where the end user can access the data. Several routing techniques introduced for WSNs are based on special features like, data aggregation and processing, in network processing, clustering, nodes' role assignment, and position of node. Therefore, routing protocols for WSNs can be classified into data-centric or flat-based, hierarchical or cluster-based and location-based, depending on the network structure. Routing protocols can also be divided into multipath based, QoS-based, query-based, and coherent-based, depending on how the protocol operates.

All nodes in a flat routing protocol are assigned equal roles or functionality and the nodes collaborate to perform the sensing tasks. The BS sends queries to certain regions within the WSN and awaits data from the sensors located in that region. SPIN (W. Heinzelman, J. Kulik, & H. Balakrishnan,1999) and directed diffusion (C. Intanagonwiwat, R. Govindan, & D. Estrin,2000) are examples of flat routing protocols. Location or position information of sensor nodes is essential to calculate the distance between neighboring nodes. If the location of sensor nodes are known then data transmission only occurs on that region to reduce the number of transmissions. GAF (Y. Xu, J. Heidemann, & D. Estrin, 2001) and GEAR (Y. Yu, D. Estrin, & R. Govindan, 2001) are examples of location-based energy-efficient routing protocols. In the cluster-based routing approach the network is divided into clusters and nodes play multiple roles in the network. Nodes in a cluster communicate with a cluster-head (CH) and the CH transmits the data to the global BS. This reduces the transmission range of normal nodes to conserve energy.

The routing protocol that uses multipath instead of a single path to increase reliability is called multipath routing protocol. Directed diffusion (C. Intanagonwiwat, R. Govindan, & D. Estrin, 2000) and proposal (R. Shah & J. Rabaey, 2002.)are examples of multipath routing. QoS-aware routing protocols minimize the end-to-end delay, energy consumption and bandwidth requirements of WSNs during data communication. In query-based routing, the destination nodes initiate a query for data from a node through the network. The nodes having the answer to the query send the data back to the parent nodes that initiated the query. Examples of query-based routing protocols are directed diffusion (C. Intanagonwiwat, R. Govindan, & D. Estrin,2000) and RUMOR (D. Braginsky & D. Estrin,2001) .Based on data processing techniques, routing protocols for WSNs comprise coherent based and non-coherent-based. Proposal (D. Braginsky & D. Estrin,2000) and directed diffusion (C. Intanagonwiwat, R. Govindan, & D. Estrin,2000) are examples of coherent and non-coherent routing protocols (J. N. Al-Karaki & A. E. Kamal, 2004; Kemal Akkaya & Mohamed Younis, 2003) .

3. QoS-Aware Routing Protocols

In traditional best-effort routing throughput and delay are the main concerns. There is no guarantee that a certain performance in throughput or delay will be ensured throughout the connection. However, in some cases where real-time or multimedia data are involved in communication, some performance guarantees in certain metrics such as delay, bandwidth and delay jitter are needed. Such guarantees can be achieved by employing special mechanisms known as QoS routing protocols. While contemporary best-effort routing approaches address unconstrained traffic, QoS routing is usually performed through resource reservation in a connection-oriented communication in order to meet the QoS requirements for each individual connection.The key design goals of QoS-aware routing protocols are to ensure optimized QoS metrics such as delay bound, energy efficiency, low bandwidth consumption while achieving energy efficiency in WSNs applications. Few recent QoS-aware protocols are surveyed in the following sections.

3.1 QoS-Aware Routing

A cluster-based linear WSN topology (S. Tang & W. Li, 2006) was introduced to support QoS and optimal energy allocation in both homogenous and heterogeneous WSNs. A multihop WSN is considered in which each CH acts as the coordinator of a cluster. Each cluster is managed by a single server fixed rate (SSFR) node with finite capacity and different data arrival rates. The CH communicates with its adjacent cluster's CH and hence data is transmitted from one cluster to another until it reaches the sink. The CH is modeled using M/M/1/K queuing system in a first come first served (FCFS) manner. The CH monitors the data loss probability (DLP) and controls data generation rate to ensure QoS requirements. DLP increases with increasing traffic load. Therefore, by continuously adjusting the data generating rate at individual clusters the DLP is optimized. Optimal energy allocation algorithm makes all clusters have the same exhaustion time and hence reduces the problem of early die in the cluster closest to the sink. The clusters with high-density nodes decrease data generating rate per node to save energy. Transmission energy is optimized by adjusting the radio range. The clusters near the sink relay data even shorter distances to reduce their energy dissipation while clusters at the rear relay over longer distances to improve the relaying efficiency. Numerical analysis shows that the DLP increases with increasing of data generating rate and drastically increases at the clusters closer to the sink. The source-to-sink delay (SSD) also increases with data generating rate but the increasing rate gradually slows as the data generating rate increases.

3.2 Energy and QoS-Aware Routing

The introduction of imaging sensors has posed additional challenges. Transmission of imaging data requires both energy and QoS aware routing in order to ensure efficient usage of the sensors and effective access to the gathered measurements. (K. Akkaya& M. Younis, 2005). The protocol finds a least-cost, delay-constrained path for real-time data in terms of link cost that captures nodes' energy reserve, transmission energy, error rate and other communication parameters. Moreover, the throughput for non-real-time data is maximized by adjusting the service rate for both real-time and non-real-time data at the sensor nodes. Main aim of this protocol is to find a delay constrained path with minimum cost. Communication cost, nodes' energy stock, error rate, and other communication parameters determine the link cost. M/M/1 queuing model is used for analysis and separate queues are used for real-time and non-real-time data. Classifier checks the incoming packet and sends to the appropriate queue. Scheduler determines the order of packets to be transmitted from the queues. End-to-end delay of a path is measured by using queuing model. The bandwidth ratio (r) represents the amount of bandwidth to be allocated both to the real-time and non-real-time traffic on a particular link. The queuing delay depends on this bandwidth ratio r. Optimal selection of r can meet end-to-end QoS requirements. After calculating costs of each link an extended version of Dijkstra algorithm (E. de Queirs Vieira Martins, M. M. B. Pascoal, & J. L. E. dos Santos, 1998) is used to find the least-cost path which meets the end-to-end delay requirements. Single-r and multi-r mechanisms are introduced to calculate end-to-end delay for a particular path and to find out an optimal value for r. The effectiveness of the protocol can be validated through the evaluation of performance parameters time to first node to die, average lifetime of a node, and average delay per packet and network throughput.

3.3 Event-to-sink reliable transport protocol

Event-to-sink reliable transport (O. B. Akan & I. F. Akyildiz, 2005) is a transport protocol for WSN that seeks to achieve reliable event detection with minimum energy expenditure and congestion resolution. The reliability of event feature is measured by the number of received data packets which is closely related to the amount of information acquired by the sink for the detection and extraction of event features. The event is reliable if the observed event reliability is greater than the desired event reliability. The reporting frequency rate f of a sensor node is the number of packets sent out per unit time by that node. The transport problem in WSN is to configure the reporting frequency f, of source nodes so as to achieve the required event detection reliability R at the sink with minimum resource utilization. The data generated by the sensors are temporally correlated to tolerate individual packet losses to the extent where the distortion D_i observed when the event features are estimated at the sink does not exceed a certain distortion bound D_{max}. Reporting frequency f can control the amount of traffic injected to the sensor field while regulating the number of temporally-correlated samples taken from the phenomenon. The desired event distortion is achieved by selecting a small f.

Relationship between the observed reliability r and the reporting frequency f shows that the reliability increases linearly with source reporting rate f, until a certain $f = f_{max}$, beyond which the reliability drops as packets are dropped due to congestion. For $f > f_{max}$ the behavior is not smooth and drop in reliability due to network congestion is more significant with increasing n. Normalized reliability = $r/R = 1$ gives a suitable point known as optimal operating region (OOR) to achieve protocol's goal. Five characteristic regions are identified: (NC, LR), (NC, HR), (C, HR), (C, LR), (OOR) considering congestion and reliability. Details of these regions are given in (O. B. Akan & I. F. Akyildiz, 2005).

The primary motive of ESRT is to achieve and maintain operation in the state OOR. So the aim is to configure the reporting frequency *f* to achieve the desired event detection accuracy with minimum energy expenditure. A congestion control mechanism serves the dual purpose of reliable detection and energy conservation. An efficient transport protocol should keep track of the reliability observed at the sink and accordingly configure the operating point. They developed methodology both for single event and multiple events. The sink must accurately detect whether the flows generated by these multiple events pass through any common nodes functioning as router.

4. Comparative Analysis of QoS-aware Routing Protocols

In QoS-Aware Routing, optimal energy allocation scheme increases network lifetime and ensures QoS under heavy traffic conditions. This protocol saves energy of the network and supports QoS. But FCFS queuing essentially relegates all congestion control to the sources and completely depends on traffic arrival time. Inappropriate control of data generating rate increases energy consumption in QoS-Aware Routing.

Energy and QoS-Aware Routing protocols have enhanced throughput and average delays. By adjusting service rate the throughput of non-real-time data is increased. Also it has good energy efficiency. But inappropriate adjustment of packet service rate introduces delay per packet and wastes energy. Energy consumption is comparatively high in multi-r mechanism.

In Event-to-sink reliable transport protocol, reliability and congestion control are achieved by changing the reporting rate of nodes. Power consumption reduces with time and minimizes overall energy expenditure by maintaining the operation in the OOR state. But regulating all sensors to have the same reporting rate may not work well with heterogeneous sensors.

5. Conclusion

Owing to their versatility and efficient features, routing protocols play an important role in the operation of energy-efficient WSNs. Therefore, they are promising research area. Based on application area and network architecture, several routing protocols have been introduced that ensure energy-efficiency to prolong the network life. In this article, we present a concise survey of QoS-aware routing protocols for Wireless Sensor Networks. QoS-aware routing protocols are designed to minimize bandwidth consumption and latency. Minimum-cost paths are selected for data communications to ensure integrity.

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