QoS-Energy aware Broadcast for Sensor Networks

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Abstract

We present QoS Geometric Broadcast Protocol (QoS-GBP), a novel broadcasting protocol for heterogeneous wireless ad hoc and sensor networks. While broadcasting is a very energy-expensive protocol, it is also widely used as a building block for a variety of other network layer protocols. Therefore, reducing the energy consumption by optimizing broadcasting is a major improvement in heterogenous sensor networking. QoS-GBP is a distributed algorithm where nodes make local decisions on whether to transmit based on a geometric approach. QoS-GBP enables a tradeoff among the need for neighborhood information (communication overhead) and the delay. QoS-GBP is scalable to the change in network size, node type, node density and topology. QoS-GBP accommodates seamlessly such network changes, including the presence of actors and mobile nodes in heterogeneous sensor networks. Through simulation evaluations, we show that QoS-GBP is very scalable and guarantees minimum delay.

1. Introduction

Heterogenous Wireless Sensor and Actor Networks (WSAN), supported by recent technological advances in low power wireless communications along with silicon integration of various functionalities such as sensing, communications, intelligence and actuations are emerging as a critically important disruptive computer class based on a new platform, networking structure and interface that enable novel, low cost, high volume applications [4, 3, 14, 20]. such as nuclear, biological and chemical attack detection and protection, home automation, battlefield surveillance and environmental monitoring [4, 9, 33].

Sensor nodes in general are extremely small, low-cost, low energy that possess sensing, signal processing and wireless communication capabilities. Sensors usually gather information about the physical world. Actor nodes are nodes capable taking decisions and then perform appropriate actions. An example of actor nodes are robots able of sensing, communicating and performing actions. Actor nodes in general are equipped with larger energy sources than sensors. Heterogeneous ad-hoc wireless networks of large numbers of such inexpensive but less reliable and accurate sensors combined with few actors can be used in a wide variety of commercial and military applications such as target tracking, security, environmental monitoring and system control.

In wireless sensor networks, it is critically important to save energy. Battery-power is typically a scarce and expensive resource in wireless devices. Current research on routing in wireless sensor networks mostly focused on protocols that are energy aware to maximize the lifetime of the network, are scalable to accommodate a large number of sensor nodes, and are tolerant to sensor damage and battery exhaustion [6, 8, 22, 36, 37, 38]. We have proposed recently an integrated power management and routing routing protocol [27] that enables tradeoffs between energy consumption and latency.

Network broadcasting is the process in which one node sends a packet to all other nodes in the network. Many applications as well as various unicast routing protocols use broadcasting or a derivation of it. Applications of broadcasting include location discovery, establishing routes and

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querying. Broadcasting can also be used to discover multiple paths between a given pair of nodes. Many routing protocols propose to use localized flooding for route maintenance.

In [12] we have introduced Broadcast Protocol Sensor (BPS) networks, explicitly designed for wireless sensor networks. While reducing energy consumption was the primary goal in our design, our protocol achieves good scalability and low latency. To achieve the primary goal of energy efficiency, we reduce the number of retransmissions by using a geometric approach. We assume that each node knows its location, which also is a requirement for various other routing protocols, sensing, target tracking and other applications. Various techniques like GPS [11], Time Difference of Arrival [31], Angle of Arrival [26] and Received Signal Strength Indicator [7] have been proposed to enable a node to discern its relative location. Recently, a range-free cost-effective solutions [18] has been proposed for the same problem.

QoS-GBP presented here is an extension of our previous work [12],[13]. While the protocol proposed in [12] guarantees the minimum overhead at the cost of some delay, QoS-GBP offers a tradeoff among the delay and the communication overhead.

The rest of the paper is organized as follows. Section 2 reviews the related work. Section 3 presents a summary of our BPS protocol. Section 4 presents QoS Geometric Broadcast Protocol . Section 5 describes our simulation model and discusses the simulation results. Section 6 concludes the paper.

2. Related work

Network-wide broadcast is an essential feature for wireless networks. The simplest method for broadcast service is flooding. Its advantages are its simplicity and reachability. However, for a single broadcast, flooding generates abundant retransmissions resulting in battery power and bandwidth waste. Also, the re-transmissions of close nodes are likely to happen at the same time. As a result, flooding quickly leads to message collisions and channel contention. This is known as the broadcast storm problem [25].

The solutions presented in [5, 15, 16] are deterministic and guarantee a bounded delay on message delivery, but the requirement that each node must know the entire network topology is a strong condition, impractical to maintain in wireless networks. Several broadcast protocols that do not require the knowledge of the entire network topology have been proposed. In a counter-based scheme [25], a node does not retransmit if it overhears the same message from its neighbors for more than a prefixed number of times and in a distance-based scheme [25], a node discards its retransmission if it overhears a neighbor within a distance threshold re-transmitting the same message.

Source Based Algorithm [28], Dominant Pruning [24], Multipoint Relaying [30], Ad Hoc Broadcast Protocol [29], Lightweight and Efficient Network-Wide Broadcast Protocol [32] utilize two-hop neighbor knowledge to reduce number of transmissions. But in large scale sensor networks, especially with high densities, the two-hop neighbor knowledge might impose very high memory overhead. A good classification and comparison of most of the proposed protocols is presented in [35].

In Gossip-based routing [17], a node probabilistically forwards a packet so as to control the spreading of the packet through the network; the probability typically being around 0.65. Though, this simple mechanism reduces the number of redundant transmissions, there is still a lot of scope for improvement.

Several data dissemination protocols [19, 34, 21] have been proposed for sensor networks to disseminate data to interested sensors rather than all sensors. A broadcast protocol is presented in [10] for regular grid-like sensor networks.

In this paper we propose a new protocol, which needs minimal neighbor-hood information; neither the neighboring node addresses nor their locations are needed. This eliminates storage overhead and communication overhead due to hello messages are needed. Another property of GBSA as illustrated through simulations is that the number of retransmitting nodes gradually decreases as the number of nodes in the network increases.

3. Broadcast Protocol for Sensor Networks (BPS)

In this Section we give a short presentation of BPS [12]. BPS was designed as a modification to *The Covering Problem* can be stated as follows: "What is the minimum number of circles required to completely cover a given 2-dimensional space." Kershner [23] showed that no arrangement of circles could cover the plane more efficiently than the hexagonal lattice arrangement. Initially, the whole space is covered with regular hexagons, whose each side is R and then, circles are drawn to circumscribe them.

We have modified the covering problem to the following algorithm, initially explained for ideal conditions. The area to be covered with radio signal is portioned into hexagons. The communication range of nodes determines the hexagons' length of sides. The Source S is at the center of one of the hexagons. In an ideal network, all other transmission nodes are at, as shown in Fig. 1. We will call the vertices of the hexagons strategic locations. The broadcasted packets are propagated along the sides of the hexagons. Any active node located inside a hexagon is reachable from at least one of the vertex nodes of the hexagon. Of course, in real conditions, it is impractical to assume that active nodes are located at the hexagons' vertices. Thus, if the active neighbor nodes are not in the optimal strategy locations, the coverage figure will be distorted; moreover, the distortion effect may propagate. A simple solution is to select the nearest active node to the supposed vertex.

It should also be observed that a node could receive a packet more than once - from different directions and from different nodes, each node specifying different optimal strategic location (because of distortion). This may cause two nodes very close to each other to retransmit. We propose to avoid these transmissions by having a node keep track of its distance dm to the nearest node that has retransmitted the packet and to have a node retransmit only when its distance to the nearest transmitting node is greater than a threshold Th.

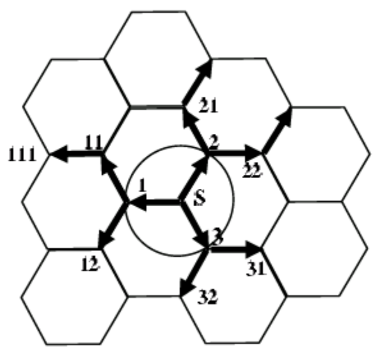

Figure 1. Our Solution for the Modified-Covering Problem

In [12] we have shown through simulations that our BPS protocol outperforms other broadcasting protocols.

4. QoS Geometric Broadcast Protocol (QoS-GBP)

In this section, we present the QoS Geometric Broadcast Protocol for heterogeneous Ad Hoc and Sensor (QoS-GBP).

We assume that each node has knowledge of its one-hop neighbors. Thus once a node decides to retransmit a broadcast packet, the node not only calculates the next strategic locations, but also computes the nearest nodes to those strategic locations and includes those node ids in the broadcast packet. Whenever a node receives a broadcast packet, it checks the packet if its id is listed in the header. If it is then it repeats the procedure.

Algorithm

Each broadcast packet contains two location fields, L_1 and L_2 in its header and a list of nodes close to strategic locations. Whenever a node transmits a broadcast packet, it sets L_1 to the location of the node from which it received the packet and sets L_2 to its own location. The Source Node *S* sets both L_1 and L_2 to its location (S_X, S_Y) and transmits the packet.

1. Upon the reception of a broadcast packet, an active node *M* discards the packet if *M* has transmitted the packet earlier, or if a node which is very close has already transmitted this packet, i.e., if $d_m < Th$. *M* continues the algorithm if it is part of the list of nodes close to the strategic location.

2. If the packet is not discarded, *M* finds the nearest vertex V (for example node 1 in Fig. 1.) of a hexagon with (S_X, S_Y) as its center coordinates and with $(S_X + R$, $S_Y)$ as one of its vertices. *M* also computes the nearest nodes to those strategic locations and includes those node ids in the broadcast packet. It computes its distance *l* from the received closest node to its strategic and then delays the packet rebroadcast by a delay d given by $d = l * R$.

3. After the delay *d* elapses, *M* determines if it has received the same packet again and if the packet can be discarded (for the same reasons mentioned above). In case *M* is the closest node to its strategic location, there is no delay in retransmission. If for some reason the closest node to the strategic location does not retransmit, delaying enables the selection of an active node that successfully received the packet and is the nest closest to the corresponding strategic location. In the case that the packet cannot be discarded, *M* retransmits.

The purpose of having the threshold *Th* is to prevent two active nodes that are very close to each other from transmitting, thus reducing the redundancy. The key factors depending on *Th* are the number of transmissions and the delivery ratio. As *Th* increases, the number of transmissions decreases. This happens because when *Th* increases, the minimum distance between any two transmitting nodes increases. This in turn implies that additional area covered increases, and hence, the number of transmissions needed for covering entire network decreases. The higher the number of transmissions, the higher is the redundancy, and therefore the greater is the probability that a node receives broadcast. Therefore, for higher delivery ratios, lower *Th* is preferred. Through extensive simulations we have found that for a threshold value of $Th = 0.35 * R$, a delivery ratio of around 98% is achieved and for $Th = 0.4 * R$, the delivery ratio is close to 95%. However, when $Th = 0.45 * R$, the delivery ratio falls to around 90%. This is understandable, because with the increase in threshold value, the number of retransmitting nodes decreases. For all further simulations, we use threshold value of $Th = 0.35 * R$.

The computational complexity of QoS-GBP is negligible; when compared to flooding, the major additional computation is finding the node's distance to the nearest optimal point according to the modified covering problem, which can be easily computed. The only bandwidth overhead due to QoS-GBP is because of addition of new header fields to carry location information of several nodes which is not significant.

5. Performance Evaluation

We have developed a simulator using OMNET++, a discrete event simulation framework [2], to evaluate the performance of our protocol. We have confirmed the results of our simulations by using the ns-2 simulator too. In [12] we compared our BPS with blind flooding. We also compared BPS with Ad Hoc Broadcast Protocol (AHBP) [29] as AHBP is one of the protocols (SBA [28] being the other) that approximates MCDS fairly [35]. A wireless network of different physical areas and different shapes with different number of nodes were simulated. The model parameters and limits on transmission bit rates and energy ratings are set according to Crossbow MICA2 sensor nodes [1]. Power consumption in the model is based on the amount of the current draw that Crossbow MICA2 sensor node's radio transreceiver uses [1].

Here we compare the performance of QoS-GBS to that of BPS (named as GBP) in case of wireless sensor networks networks.

Fig. 2 compares the performance in terms of number of retransmissions of QoS-GBP and GBP for a 8×8 network with varying densities. In ideal MAC conditions, the performance of the protocols should be same because same set of nodes will be selected to retransmit the broadcast packet. We observed this to be true. As shown in Fig. 2, the performance is almost same for both the protocols.

Fig. 3 shows the average time taken to finish the broadcast process. The time is measured from the moment the broadcast message is initiated by the source node till the moment the last broadcast message was transmitted in the network.

In case of QoS-GBP, the broadcast time slightly decreases as density increases. The reason is that at higher densities, the approximation of the ideal solution is higher, resulting in lesser number of transmissions and also shorter maximum hop-length to reach any node in the network. This results in lower broadcast time at higher densities. The broadcast time for GBP decreases significantly as density increases. At lower densities, as shown in Fig. 3, the delay per hop due to the counter is higher and this delay decreases

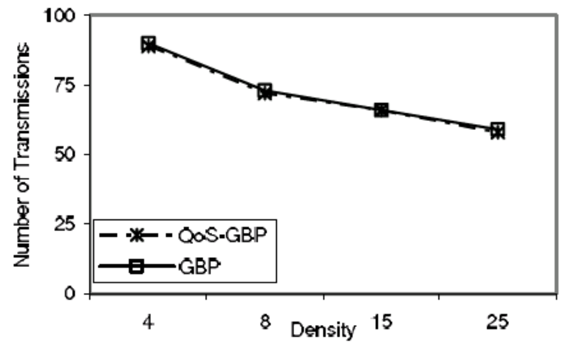

Figure 2. Number of transmissions vs. network density

rapidly as density increases. Thus, the broadcast time significantly decreases at higher densities.

In fact this Fig. 3 shows a direct tradeoff between latency and energy. QoS-GBP is quick in performing the broadcast mechanism, but at the cost of hello messages to maintain up-to-date neighbor knowledge. At the same time, GBP (BSP in [12]) uses almost same number of retransmissions to perform the broadcasting but it takes longer duration to finish the process. The advantage is that there is no need of neighbor knowledge which implies that there is no need for hello messages.

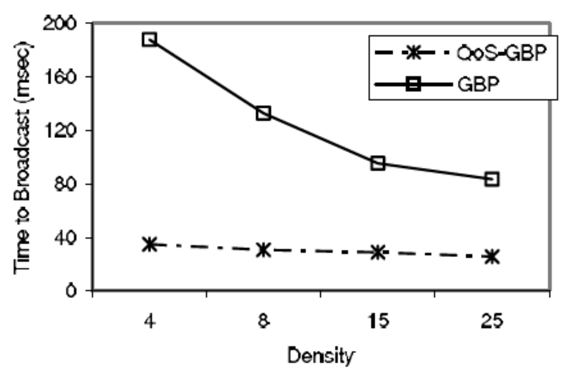

Figure 3. Time to broadcast vs. density

We also compare the performance in the scenario of mobile nodes. Each node is constantly moving at a random speed between 0 and *x*, where *x* is varied up to 20 m/s. The results are presented in Fig. 4 . We observe that the performance of QoS-GBP deteriorates as the speed increases. This is because at higher speeds the chances that the neighbor information at a node is outdated is higher. Interestingly, GBP maintains its performance even in mobile networks showing that its performance is indeed independent of neighbor locations. We considered hello interval of 15 seconds for these simulations.

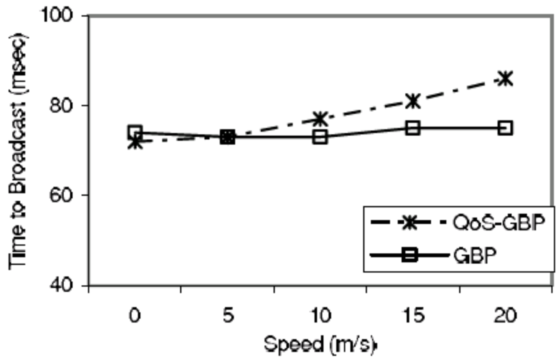

Figure 4. Time to broadcast vs. speed of nodes

6. Conclusion

We presented QoS Geometric Broadcast Protocol, a novel protocol for use in heterogeneous Wireless Ad Hoc and Sensor Networks.

QoS-GBP is a distributed algorithm where nodes make local decisions on whether to transmit based on a geometric approach. QoS-GBP enables tradeoff between the broadcast delay and communication overhead (hello messages needed to keep neighbor information)

QoS-GBP is scalable to the change in network size, node type, node density and topology. Through simulation evaluations, we showed that QoS-GBP is very scalable and guarantees low broadcast delays.

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