Geometric Broadcast Protocol for Sensor and Actor Networks

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Abstract

We present Geometric Broadcast for Sensor and Actor Networks (GBSA), a novel broadcasting protocol for heterogeneous wireless sensor and actor 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 heterogeneous sensor networking. GBSA is a distributed algorithm where nodes make local decisions on whether to transmit based on a geometric approach. GBSA does not need any neighborhood information and imposes very low communication overhead. GBSA is scalable to the change in network size, node type, node density and topology. GBSA accommodates seamlessly such network changes, including the presence of actors in heterogeneous sensor networks. Indeed, GBSA takes advantage of actor nodes, and uses their resources when possible, thus reducing the energy consumption by sensor nodes. Through simulation evaluations, we show that GBSA is very scalable and its performance is improved by the presence of actors. At best of our knowledge, GBSA is the first broadcast protocol designed specifically for heterogeneous sensor and actor networks.

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, 9, 32]. 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, 21, 35, 36, 37]. We have proposed recently an integrated power management and routing protocol [26] 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 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 scala-
ibility 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 [30], Angle of Arrival [25] 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 [17] has been proposed for the same problem.

GBSA presented here is an extension of our previous work [12]. GBSA handles seamlessly the presence of actors, by using their resources at the advantage of other nodes with less energy. The final result of GBSA is less retransmitted packets, which leads to less energy consumed by sensors and faster transmission coverage of a given area. At best of our knowledge, GBSA is the first broadcast protocol designed specifically for heterogeneous sensor and actor networks.

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 Geometric Broadcast for Sensor and Actor Networks. 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 [24].

The solutions presented in [5, 14, 15] 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 [24], 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 [24], a node discards its retransmission if it overhears a neighbor within a distance threshold re-transmitting the same message.

Source Based Algorithm [27], Dominant Pruning [23], Multipoint Relaying [29], Ad Hoc Broadcast Protocol [28], Lightweight and Efficient Network-Wide Broadcast Protocol [31] 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 [34].

In Gossip-based routing [16], 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 [18, 33, 20] 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.


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 [22] 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.

A modified version of the Covering Problem can be stated as follows: “What is the minimum number of circles of Radius R required to entirely cover a two-dimensional space with the condition that the center of each circle being placed lies on the circumference of at least one other circle.”

If the range of a node is considered to be R, then the reason behind the condition that the center of a circle should lie on the center of another circle is that a node has to receive a message for it to retransmit the message. A possible solution for the Modified-Covering Problem is shown in Fig. 1. As done for covering problem, initially the whole region is covered with regular hexagons whose each side is R. Then, with each of the vertices as a center, circles of radius R are drawn.
The following properties of the vertices in Fig. 1 should be noted:

- **Property-1**: Each vertex $v$ is joined to three other vertices.
- **Property-2**: The lines joining these three vertices to vertex $v$ make an angle of $120^\circ$ ($2/3$ radians) with each other.
- **Property-3**: Each vertex is at a distance of $R$ from each of its neighboring vertices.

Thus, given a vertex $v$ and one of its neighboring vertices, using the above properties, it is very easy to determine the other two neighboring vertices of vertex $v$. The approach followed here to solve the Modified-Covering problem is for an ideal case scenario. We use the same approach to achieve broadcasting in a more general case, where there need not be any node at the optimal locations. In this case Fig. 1 can get skewed considerably. Even when the skew is very large, the number of transmissions required to cover the whole region remains very low.

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

## 4. Geometric Broadcast for Sensor and Actor Networks (GBSA)

In this section, we present the Geometric Broadcast for Sensor and Actor Networks (GBSA) for wireless sensor and actor networks. We make use the fact that actor nodes are more powerful and have more energy/transmission radius than sensor nodes. Thus, an actor node can cover lot more area than a normal sensor node and hence we would like the actor nodes to transmit first and then sensors to transmit.

We assume that each sensor node knows the location of its nearest actor node and to how many actor nodes the sensor is a neighbor. We also assume that each actor node knows the locations of other actor nodes. Let $S$ be the Source node that generates the broadcast message. $S$ sends the broadcast message first to one of the actor nodes, which in turn sends it to other actor nodes (if present). The actor nodes then broadcast the message to all of their neighbors, resulting in coverage of a large portion of the network. Then, only few other sensors (that are selected based on some criteria described later in this section) transmit to cover the remaining region.

### Algorithm

Let $R$ be the transmission range of a sensor and $R_a = k \times R$ be the transmission range of an actor node. The protocol execution at the actor nodes is different from that at sensor nodes. The header of a broadcast message is formatted to contain $3 \times k$ locations if being transmitted by an actor or two locations $L_1$ and $L_2$ if being transmitted by a sensor.

#### 4.1. Actor Node Algorithm

The protocol executed at the actors is described below:

1. The source node that generates the broadcast message sends the packet to its nearest actor which in turn forwards it to other actor nodes (if present) in the network.
2. Each actor calculates $3 \times k$ strategic locations as follows:
   - The actor selects some point $P$ randomly on its circumference.
   - The remaining $3 \times k - 1$ points are the points on the circumference such that each is at a distance of $2R$ from other points.
3. The actor broadcasts the packet with these $3 \times k$ points stored in the header of the packet.

#### 4.2. Sensor Node Algorithm

The protocol execution at sensor nodes is as follows:

1. A node $M$, upon receiving a broadcast packet, first determines if the packet can be discarded. A packet can be discarded under any of the following conditions:
   - If the node has transmitted the packet earlier.
   - If a node which is very close has already transmitted this packet, i.e., if $d_{on} < Th$.
   - The node $M$ is a neighbor of more than one actor node.
2. If the packet is not discarded, $M$ determines if it received the packet directly from an actor node.

   - If yes, $M$ first finds the location $L$ in the header of the message that is closest to. It computes its distance $l$ from $L$ and then delays the packet re-broadcast by a delay $d$ given by $d = \frac{l}{R}$.
   - Else, if $M$ has not received the packet directly from the source $S$, but from some other node $K$, then using properties 1, 2 and 3 mentioned in section 3 and with the nearest strategic location. The packet transmission is delayed by $d = \frac{1}{20} \times R$.

3. After delay $d$, $M$ again determines if it has received the same packet again and if the packet can be discarded (for the same reasons mentioned above). Thus, delaying enables a node to decide if it is the nearest node to the strategic location. $M$ updates $L_1$ to location of the node from which it received the packet and $L_2$ to its location, sets $d_n$ to zero and transmits, if the packet cannot be discarded.

   A node $M$ does not broadcast a message if it is a neighbor of more than one actor. This is because, in such a scenario, $M$ is in the overlap region of the coverage regions of the actors and so is the case of most of neighbors of $M$. Thus, even if $M$ retransmits the message, most of the cases it would not reach any sensor that is not covered by the actors.

   Fig. 2 shows the intuition behind the selection of $3 \times k$ locations when $R_n = 2 \times R$. The delay is used to make a node decide if it is the nearest node to the strategic location. Low delay values decrease the time needed to broadcast a message all over the network, while high delay values help reduce redundant transmissions in instances where two nodes are of about same distance from the strategic location. The delay function we used causes a packet to be delayed a maximum of 50 ms per retransmission, though typically this value lies around 10 ms. In dense networks, the delay values are much less than 10 ms.

![Figure 2. Broadcasting from an Actor node](image)

The computational complexity of GBSA 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 using properties 1-3 mentioned in Section 3. The only bandwidth overhead due to GBSA is because of addition of new header fields to carry location information of two 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. In [12] we compared our BPS with blind flooding. We also compared BPS with Ad Hoc Broadcast Protocol (AHBP) [28] as AHBP is one of the protocols (SBA [27] being the other) that approximates MCDS fairly [34]. A wireless network of different physical areas and different shapes with different number of nodes were simulated.

Here we compare the performance of BPS to the extended broadcast protocol GBSA in case of heterogeneous wireless networks that include both sensor and actor nodes.

We consider two different network scenarios:

1. Wireless Sensor Networks (WSNs) consisting of different kinds of sensors. Sensor nodes of various (but similar) capabilities are assumed to be present and the each sensor can be sensing different phenomenon.

2. Wireless Sensor and Actor Networks (WSANs) consisting of sensor nodes of same capabilities along with some actor nodes.

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 transceiver uses [1].

In Fig. 3 is shown for a network of $10R \times 10R$ with two actor whose radius is $3R$. There are 625 nodes and 3.8% nodes are uncovered with 64 transmissions. In the figure it is shown the effect of skew in case of random distributed nodes.

Figure 4, 5 and 6 present the performance of GBSA in a sensor network for different network size, density and network configuration. As expected, GBSA is very scalable, the number of transmissions is being reduced when the density increases. The reason for this is the geometric approach used in GBSA. We have compared network configuration with and without actors. As shown by results of 4, 5 and 5 GBSA takes advantage of the presence of Actors to reduce the number of retransmissions, therefore lowering the energy consumption and increasing the speed to cover the whole area.
6. Conclusion

We presented Geometric Broadcast for Wireless Sensor and Actor Networks (GBSA), a novel protocol for use in heterogeneous Wireless Sensor and Actor Networks.

GBSA is a distributed algorithm where nodes make local decisions on whether to transmit based on a geometric approach. GBSA does not need any neighborhood information and imposes very low communication overhead.

GBSA is scalable to the change in network size, node type, node density and topology. GBSA accommodates seamlessly such network changes, including the presence of actors in heterogeneous sensor networks.

Indeed GBSA takes advantage of actor nodes, and uses their resources when possible, thus reducing the energy consumption by sensor nodes. Through simulation evaluations, we showed that GBSA is very scalable and its performance improves by the presence of actors.

References


