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A Location Routing Protocol based on Smart Antennas for Wireless Sensor Networks

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Abstract

The task of finding and maintaining routes in a Wireless Sensor Networks is a nontrivial task since energy restrictions and sudden changes in node status (e.g. failure) cause frequent and unpredictable topological changes. This work introduces a novel location routing protocol that uses smart antennas to estimate nodes positions into the network and to deliver information basing routing decisions on neighbor's status connection and relative position, named LBRA. The main purpose of LBRA is to eliminate network control overhead as much as possible. To achieve this goal, the algorithm employs local position for route decision, implements a novel mechanism to collect the location information and involves only route participants in the synchronization of location information. In addition, the protocol uses node battery information to make power aware routing decisions. In order to asses LBRA a series of simulations were designed with the help of the Network Simulator 2 (ns2). The experiment results showed that LBRA succeed in reducing the control overhead and the routing load, improving the packet delivery rate. Additionally, network power depletion is more balanced, since routing decisions are made depending on nodes' battery level.

Keywords: Local Positioning, Routing Protocol, Smart Antennas, Wireless Sensor Networks

1. Introduction

Wireless Sensor Networks (WSNs) are an emerging technology for low cost, unattended monitoring of a wide range of environments[1]. One of the most important constraints of sensor nodes is the low power consumption requirement since they carry limited, generally irreplaceable, batteries. In addition, they are also characterized by scarce processing speed, storage capacity and communication bandwidth, thus requiring careful resource management.

Due to the inherent characteristics and restrictions of sensor nodes, routing in WSNs is very challenging. The task of finding and maintaining routes is nontrivial since energy restrictions and sudden changes in node status (e.g. failure) cause frequent and unpredictable topological changes[2]. Although many routing algorithms for WSNs have been proposed, the authors in[3] establish that routing protocols that do not use geographical location information are not scalable and in[4] is set that ideal routing protocols for WSNs should base routing decisions on information exchanged with neighbors, offer network reliability and require minimal message overhead, power consumption and memory footprint. For these reasons most of the research on routing in WSNs has focused on localized or position-based protocols. Localized routing algorithms avoid control-traffic overhead by requiring only accurate neighborhood information and a rough idea of the position of the destination which is extremely suitable for networks with critical power-constrained resources at nodes such as WSNs[5]. Besides, location information can also be used to identify a data source for application requirements; however, the use of localized protocols poses evident problems in terms of reliability.

The accuracy of the destination's position is an important problem to consider. The simplest method to resolve the location problem is to provide all nodes with a GPS receiver that would allow assigning real coordinates to nodes into the network. However, this is an expensive solution due to GPS receiver's cost, power consumption and size requirements. A novel approach, that remained until recently unexplored, is the use smart antennas to estimate nodes positions accurately and to improve network communication, decreasing power consumption and therefore increasing its life cycle. A smart antenna is an antenna composed of many antenna elements that are arranged in a linear, circular or planar configuration. Their role is to increase the radio signal quality by optimizing radio propagation and to increase medium capacity by increasing bandwidth utilization. Their smartness resides in the combination of the signals received within the smart antenna elements[6]. Smart antennas in general have been for long considered unsuitable for integration in wireless sensor nodes. They consist of more than one antenna element and therefore require a larger amount of space than traditional antennas. In addition to that, the processing of more than one signal requires more computational power and electronics capable of translating Radio Frequency (RF) signals to base band signals suitable processing. However, it has been experimentally demonstrated that the use of smart antennas can increase overall network capacity and significantly reduce power consumption. Moreover, it has been shown that the use of smart antennas in sensor networks is in some cases obligatory and in other cases achievable, with minimal additional cost[6–8].

This article presents a novel location routing protocol LBRA (Location Based Routing Algorithm) based on smart antennas for Wireless Sensor Networks.

2. Related Work

Routing in WSNs is generally classified based on network structure as *flat*, *hierarchical*, or *location* based[2]. In *location-based* routing, sensor nodes' positions are exploited to route data in the network and sensor nodes are addressed by means of their position. In this kind of routing, location information is used by protocols to calculate the distance between two particular nodes so that energy consumption required for communication can be estimated. To save energy, some location-based schemes demand that nodes go to sleep if there is no activity, having as many sleeping nodes in the network as possible[9]. The main advantage of location-based routing lies in its efficiency in the sensor memory utilization. The overhead incurred by the other types of routing due to maintaining routing table is "*quadratic in network*[10]" as a result of topological changes in the network. Whereas location-based routing algorithms only need accurate neighborhood information (i.e., position of the neighbor nodes) and position information of the sink to find a good route[11]. Positions of the nodes can be obtained from low power GPS receivers or relative coordinates can be found using different techniques[9]. Besides, location-based routing schemes are highly scalable and robust against frequent topological changes. They can reduce transmission and processing overhead by minimizing neighborhood information exchange, and can minimize memory usage by not maintaining routing tables[12].

In the literature we can find a lot of implementations of location-based routing protocols. Some of them are the following ones. The *Greedy Perimeter Stateless Routing*[13] (GPSR) protocol is a non-energy aware protocol that uses nodes location and packet destination to make packet forwarding decisions. Under GPSR, packets are marked by their originator with their destination's locations. As a result, a forwarding node can make a locally optimal greedy choice in choosing a packet's next hop. Specifically, if a node knows its neighbors' positions, the locally optimal choice of next hop is the neighbor geographically closest to the packets' destination. Forwarding in this scheme follows successively closer geographic hops until destination is reached. However, a problem may occur when such a neighbor does not exist and the current node is closer to the destination than any of its neighbors (dead end). When a packet reach a dead end, the protocol switches to perimeter forwarding and uses the right hand rule to take tours of enclosed cycles in a planarized network graph. Upon receiving a greedy-mode packet for forwarding, a node searches its neighbor table for the neighbor geographically closer to the destination. If this neighbor exists the node forwards the packet to it, otherwise, the node marks the packet into perimeter mode. GPSR forwards perimeter-mode packets using a simple planar graph traversal (a graph in which no two edges cross). Perimeter forwarding is only intended to recover from a local maximum; once the packet reaches a location closer than where the greedy forwarding previously failed, the packet can continue greedy progress toward the destination without danger of returning to the prior local maximum. GPSR and other similar algorithms based on graph planarization are not perfect. Inaccuracies in position estimates and irregular radio ranges (possible due to obstacles) may result in errors in the planarization procedure causing routing failures and infinite loops. On top of that, this recovery procedure requires calculating and maintaining planar graphs information at every node, which is highly inefficient given that this information is rarely used[14].

Until recently, research in smart antenna systems in the area of sensor network has been prohibitive due to size, cost, and power considerations. Smart antenna technology implemented within sensor network hardware platforms seems contradictory. On the one hand, sensor nodes are extremely sensitive to power consumption, computational power, size and cost. On the other hand, smart antenna systems not only require larger amount of space (to handle multiple antenna elements), but also more computational power (since signals from the set of antenna elements are processed and controlled in order to make communication more efficient), and more electronic elements capable of translating Radio Frequency (RF) signals to baseband signals suitable for processing[15]. Conversely, the use of smart antennas in sensor nodes is not only feasible, but also desirable. As sensor node dimension shrinks, RF communication will be forced to utilize higher frequencies. Fundamental theory states, however, that transmission using higher frequencies results in lower effective communication ranges. To compensate for distance loss, higher gains have to be achieved. Increased gains, which can be attained using smart antennas, are necessary to preserve connectivity in networks and efficiently use a sensor node's energy source[8,15].

The advantages of using smart antennas in ad-hoc communications has been demonstrated using small-scale and large-scale fading models in[16] where improvements of 20dB in received Signal Noise Ratio (SNR) were reached and the bit error rate was reduced by more than 60%. Moreover, the use of smart antennas can be significantly decrease the nodes' power consumption, and therefore increase their lifecycle[8]. In addition, according to[15], integrating the smart antenna scheme into the sensor hardware platform increases the total cost of the design by only 3%. Finally, according to[17], the incorporation of smart antennas on WSNs nodes resulted in approximate improvements in the quality of service by 20%, the efficiency by 50% and the percentage of active nodes by 20% and the energy consumption by 50%.

In[8], the authors propose a new family of protocols that try maximizing efficiency and minimizing energy consumption by favoring certain paths of local data transmission towards the sink by using switched beam antennas at the nodes. Just like flooding, the protocol requires nodes to forward every new incoming packet, avoiding network resources depletion by restricting the nodes that receive and hence retransmit the message with the use of switched beam antennas. The mechanism that controls this propagation of information is the following: during the initialization phase of the network, the base station transmits a beacon frame with adequate power to be able to reach all the network's nodes. Each node switches among its diverse beams and finds the one that delivers the best signal. After the initialization phase, the nodes will use this beam only for transmitting data, and they will use the beam lying on the opposite side of the plane only for receiving data. During normal operation, nodes retransmit every new incoming packet that has not received before. The main drawback of this approach is the need to reconfigure the entire network when a topological change happens.

To the best of our knowledge, this work is the first attempt to use smart antennas in order to create an energy-efficient location-based routing protocol for Wireless Sensor Networks. This is the main contribution of our research.

3. Proposed Solution

The previous section introduced some of the existing location-based routing strategies for wireless sensor networks and exposed the reasons for which data routing in this type of networks supposes a true challenge. In the same way, recent advances reached in the implementation of smart antenna technology within sensor networks were presented. We could observe the potentialities of the exploitation of smart antennas in WSNs. The more trivial benefits coming from such integration are: a higher capacity in wireless links by effectively reducing multipath and co-channel interference, improving network communication and decreasing power consumption, thus increasing its lifecycle[18]. Additionally, they allow making an accurate estimation of nodes positions without requiring additional components[19].

In this section, we present the Location Based Routing Algorithm (LBRA), a routing algorithm for WSNs that uses smart antennas to get the node's location. This novel algorithm will satisfy following criteria: loop free transmission, efficiency in energy management, scalability, node failure tolerance, node heterogeneity and guaranteed delivery.

3.1 Absolute Position vs. Relative Position

The development of localization work made location-based routing possible. We can make full use of the location information of nodes for route discovery. Location-based routing protocols are less complicated and easier to implement than cluster-based routing protocols and more energy efficient than flat-based routing protocols due to reduced flooding since these protocols require only accurate neighborhood information and a rough idea of the position of the destination eliminating the necessity to set up and maintain explicit routes, reducing communication overhead and routing table size. However, getting the location of a node is not a trivial task.

One possibility to deal with the location problem would be to manually assign node's location, which is often impractical or impossible due to the number of nodes or the method of deployment. Another option could be to equip all nodes with a GPS receiver which will provide the absolute or global position of each node. However, this is an expensive solution due to GPS receiver's costs, power consumption and size requirements which are inappropriate for resource-constrained networks. It may also fail to work if some nodes cannot receive GPS signals (for example it cannot be used for indoor applications). A cheaper alternative would be to equip with GPS receivers (or manually provide correct coordinates) only a few anchor nodes and, according to these, approximate the coordinates of other nodes.

Smart antennas receive radio signals and collect information such as AoA (Angle of Arrival), TDoA (Time Difference of Arrival) and phase of the signal at arrival and process it by the means of an embedded digital circuit being only able to locate nodes in their range. Thus, when combined with a relative-position based routing algorithm, a node knows its neighbors' status of connections and relative positions, which makes the route decision making process very simple. By contrast, in a global-position based routing algorithm, before route decisions can be made, nodes must synchronize the global position throughout the network, calculate the network coordinates and work out the connectivity map (highly variable), which makes the routing decision process more complex[20]. Due to the limits imposed by the use of absolute position in highly constricted networks such as WSNs and considering the technical specifications of smart antennas previously described, in this work we propose to use relative position.

3.2 The Location based Routing Algorithm (LBRA)

The main purpose of our proposed routing algorithm, LBRA (location based routing algorithm), is to eliminate network control overhead as much as possible. To achieve this goal, the algorithm employs nodes' position for route decision, implements a novel mechanism to collect the location information and involves only route participants in the synchronization of location information. In addition, the protocol uses node battery information to make power aware routing decisions.

A few assumptions before presenting our solution:

- All nodes are equipped with smart antennas, thus being able to identify their neighbor's connection status and relative position by the incoming radio waves.
- All nodes in the network are energy constrained.
- All nodes in the network play the same role within the routing process, which essentially means that every sensor node is able to perform routing tasks.
- Each sensor node is outfitted with a battery and at the beginning all nodes in the sensor field have the same energy level.
- All nodes have a mechanism to know the remaining battery level.
- All nodes in the network know the position of the sink.

LBRA is prototyped from AODV (which has become a milestone of reactive algorithms) and has three parts: Route Discovery (RD), in which nodes seek routes to communicate among themselves, Route Establishment (RE), in which nodes set up two-way connections by the exchange of the required information, and Route Maintenance (RM), that poses a mechanism to select the best route in terms of energy consumption among the routes found during the Route Discovery stage. The Route Discovery in its turn is divided into two stages: Route Request (RREQ), in which a source node searches for a specific destination node in the network, and Route Reply (RREP) that allows, once the destination node is found, the establishment of the two-way communication path between the nodes. Every node will have a Routing Table (RT) and a Route Discovery Table (RDT) that will be constructed/updated during the RD phase. The basic information contained in the RT and in the RDT is shown in Table 1 and Table 2 respectively.

Table 1. LBRA routing table

Field Name	Description
Pre-hop Address	Location of the previous hop from the source
Next-hop Address	Location of the next hop towards the sink
Entry status	Status of the route: Active, Discovery or Inactive
Expiration Time	A countdown timer indicating the number of milliseconds until the route entry expires

Table 2. LBRA route discovery table

Field Name	Description
RREQID	Sequence number of the RREQ message
Source Address	Location of the RREQ initiator
Sender Address	Location of the device that sent the most recent lowest cost route request
Relay Cost	The accumulated path relay cost from the RREQ initiator to the current device
Reverse Relay Cost	The accumulated path cost from the current device to the destination device
Expiration Time	A countdown timer indicating the number of milliseconds until the route entry expires

3.3 Route Discovery

Route Discovery (RD) is a process that allows nodes to collect and record the necessary information to communicate or to act as relay entities according to the case. In this stage, RT and RDT entries in the nodes along the path between two nodes wishing to communicate are created. In LBRA there are two possible scenarios for the RD process: flooding and limited flooding (concept originally proposed in[21] for mobile ad hoc networks). The choice of the scenario will depend on the awareness of the sink's position: if the source node knows the location of the sink node, it uses the limited flooding; otherwise, it floods the entire network. The propagation algorithm to flood the network is similar to the one used by the ZigBee AODV route discovery process[22]. When a source node *S* needs to communicate with the sink, it broadcasts an RREQ message to all its neighbors. Each route request message is uniquely identified by a conjunction of the Source Node Identifier (SID) and an RREQ Identifier (RREQID) that is incremented by the originator every time it sends a new RREQ message. Upon reception of the RREQ, an intermediate node *J* broadcasts the RREQ to its neighbors. To avoid loops, before forwarding the packet, *J* verifies the SID and RREQID to check if the message has been previously received. If so, the redundant RREQ is dropped.

Given that the *route request* is disseminated to several nodes by using the flooding algorithm, the path followed by the message will be included in the RREQ packet. Once the route request is received by the sink node, it responds to the originator by sending a *route reply* message (RREP) using the reverse path followed by the route request received, in the same way as AODV[22]. It is always possible that the sink node does not receive a *route request* message due to different circumstances such as transmission errors or because the sink node might be unreachable from the sender at a certain moment. In order to control that, when launching a *route discovery*, the sender sets a timeout. If by the end of this time out no reply message is received, a new *route discovery* request is started.

Time-out may also arise when the route reply message from the destination is lost. The *route discovery* process is started either when the source node does not know a route to reach the sink node, or when a route previously established between them is no longer available. In this latter situation, since nodes have already had communication, location information is available and instead of flooding the whole network looking for a route, LBRA will switch to the limited flooding scenario, restricting the flooding to a specific area called the *Target Zone*. Let's consider a node *S* that needs to set up a route to the sink, and it knows the location of its neighbors. In this case, node *S* defines a *Target Zone* for the *route request*, sending the message only to certain neighbor nodes located within a "*cone*"[23] that has *S* as its vertex, the line connecting S and the sink as its axis and the initial opening angle of 20°. Figure 1 illustrates the *Target Zone* setup for the limited flooding.

If after a suitable timeout period (calculated experimentally) a route between nodes *S* and the sink has not been discovered, the node *S* will start a new *route request* with an extended *target zone*. The way to extend the target zone is widening the opening angle of the "*cone*". In this case, however, the latency in determining the route from *S* to the sink will be higher since more than one route request will be necessary. The source node will recognize that a route is broken if, by sending a data packet to the destination node, it receives a *route error* message. A node *J* belonging to that route will send a *route error* message if upon reception of a data packet the next hop on the route is broken. As soon as the source node gets the route error message, it triggers a route discovery for the sink, using the limited flooding scenario. To be able of determining whether the next hop on the route is working properly or not, every node will send periodic **`hello`** messages, with frequency **`hello_time`** milliseconds, to the nodes that appear in its routing table as pre-hop (i.e. predecessors), only in Active routes; the neighbors that receive this packet keep record of the connectivity information. Failing to receive **`max_hello_loss`** consecutive **`hello`** messages is an indication that the next hop is out of order and therefore, in the event a data packet must be transmitted to it, a *route error* message will be generated in return.

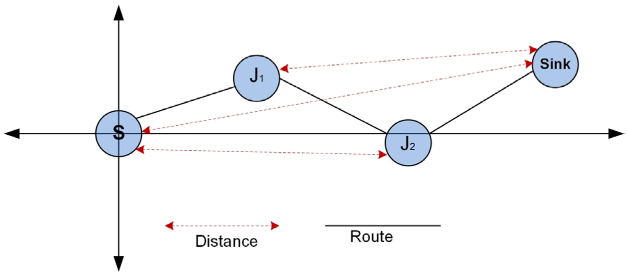


Figure 1. Target zone setup for the limited flooding.

3.3.1 Route Request

In LBRA, besides setting up connections between nodes, the flooding is also used to synchronize the location information throughout the network. Initially, a source node *S* wanting to communicate with the sink node will be unaware or poorly aware of the distribution of the network. Hence, when *S* triggers the *route request*, it will set its location as P_S^S (0,0) in the RREQ package and the position information will be updated hop by hop until the packet arrives at the sink node[20]. Figure 2 illustrates an example of the synchronization procedure of a network with 4 nodes. To follow such example let's start with some definitions:

- V: Represents the set of neighbors of a node.
- V_s: Represents the set of neighbors of node *S*.
- P_S^J: Represents the relative position of *S* in the coordinate system of node *J*.
- x_S^J: Position on the *x* axis of node *S* in the coordinate system of node *J*.
- y_S^J: Position on the *y* axis of node *S* in the coordinate system of node *J*.
- $P_S^J = (x_S^J, y_S^J)$.

The procedure to follow to establish the location is:

- *S* triggers a route request.
- Node $J_1 \in V_S$ receives the RREQ and fixes the position of *S* with respect to its own coordinate system.
- Node J_1 forwards the RREQ to its neighbor J_2.
- Node $J_2 \in V_{J1}$ receives the RREQ message and fixes the position of *S* by combining the position of *J1*, with respect to its own coordinate system, and the position of *S* with respect to the coordinate system

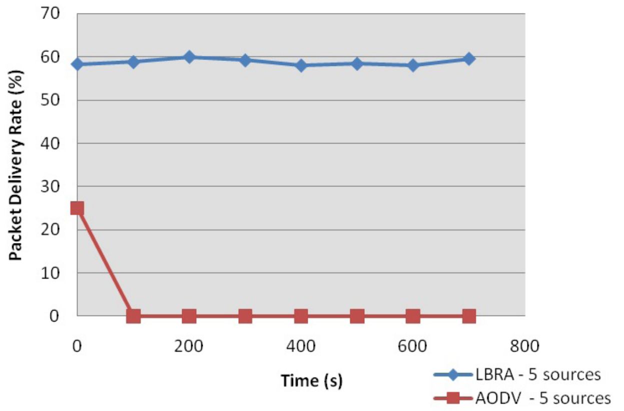


Figure 2. Location synchronization.

of *J1* included in the RREQ received. The calculation is presented in the Equation (1).

$$P_S^{J_2}(x_S^{J_2}, y_S^{J_2}) = P_{J_1}^{J_2}\ (x_{J_1}^{J_2}, y_{J_1}^{J_2})\ + P_S^{J_1}\ (x_S^{J_1}, yS,$$
$$\therefore P_S^{J_2}(x_S^{J_2}, y_S^{J_2}) = P_S^{J_2}\ (x_{J_1}^{J_2} + x_S^{J_1}, y_{J_1}^{J_2} + y_S^{J_1}) \tag{1}$$

Following this procedure, location information is synchronized throughout the network and eventually, with the reception of the RREQ message, the sink node will know the location of *S* with respect to itself and somehow the path that must follow to reach it. Location information will be used from that moment to make routing decisions. An additional task accomplished by the RREQ message while circulating throughout the network, is to get the route relay cost value that corresponds to the sum of the cost of using the nodes belonging to the route that is being explored. Then, if we have a route $R = \{n_1, n_2, \ldots, n_L\}$, we define the *relay cost* of *R*, *C(R)* as,

$$C(R) = \sum_{i=1}^{L} C\{n_i, \mathrm{n}_{i+1}\} \tag{2}$$

where $C\{n_i, n_{i+1}\}$ corresponds to the cost of traversing the link between n_i and n_{i+1}. Seeing that the energy is an important factor in the utilization of a WSN, we decided to use the energy consumption in sending data on a link as our link cost. To measure this energy consumption, we will use the model presented in (24). According to this model, the energy spent by the transmitting node n_{i} to transmit a *k*-bit packet to its neighbor node $n_{\mathrm{i+1}}$, separated from n_{i} a distance *d*, is

$$E_t(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \tag{3}$$

And the energy spent by the receiving node $n_{\mathrm{i+1}}$ to receive a *k*-bit packet is

$$r(k) = E_{elec} \times k \tag{4}$$

Where the constant E_{elec} corresponds to the energy dissipated to run the radio transmitter or receiver circuitry and the constant E_{amp} corresponds to the energy dissipated to run the transmit amplifier. Deriving from the above equations, the cost incurred by the sensor node n_{i} for transmitting a *k*-bit packet is:

$$C\{n_i, n_{i+1}\}(k) = 2 \times E_{elec} \times k + E_{amp} \times k \times d(n_i, n_{i+1})^2 \tag{5}$$

3.3.2 RREQ Process

Upon reception of an RREQ message, a node *J* searches within its RDT an entry matching the requirement. If the entry exists, *J* compares the relay cost stored on the table with the one of the RREQ received. If the former is lower the RREQ is discarded, otherwise the RDT entry is updated with data from the RREQ. In the case where no entry matches the RD, a new RDT entry is created. At the end, *J* verifies whether the RREQ is addressed to itself (*J* is the sink node) or not (*J* is an intermediate node). If *J* is not the sink, it sets an RT entry for the destination node with status `Discovery` and broadcasts the RREQ to its neighbors (using flooding or limited flooding depending on the scenario). Otherwise, it replies to the RREQ sender with a route reply (RREP) message that travels along the reverse path followed by the RREQ.

3.3.3 Route Reply

The RREP message is created by the sink node and addressed to the originator of the RREQ to indicate that a route between them has been found. To reach the source node, the RREP simply backtracks the way followed by the RREQ message. As the RREP message circulates on its way back to the source, all intermediate nodes will record the complementary data to establish the two-way path, so that the sink node can communicate with the source node. In a similar way as with the RREQ, before sending the RREP towards the source, the sink node sets its location information as P_D^D (0,0) and the location of the source node, according to what obtained in the calculations, as $P_S^D\,(x_S^D\ , \mathrm{y}_S^D)$. Upon reception of the RREP, an intermediate node *X* transforms the location information to its own coordinate system, updates the RREP message and forwards it to the next hop. At a given time the RREP will reach the source node establishing a bidirectional route.

3.3.4 Route Establishment

Upon reception of a route reply message (RREP), an intermediate node *J* retrieves the RDT and RT entries corresponding to the *Route Discovery* process that is being treated, and compares the *back relay cost* from the RREP with the one from the RDT entry. If the former is bigger, the RREP is discarded; otherwise the RDT (*back relay cost*) and the RT (*next hop, pre-hop*) entries are updated and the RREP is forwarded to the next hop. When the first RREP message reaches the RREQ originator, this one sets the *Entry Status* of the RT entry to **`Active`** and updates the *back relay cost* and *next hop/pre-hop* information in the RDT and in the RT respectively. For all subsequent RREP messages, it compares the *back relay cost* with the one on the RDT entry, discarding the message or updating the tables as the case. Intermediate nodes will only change the *Entry Status* to **`Active`** upon reception of the first data message for the given destination.

3.3.5 Routing Table Maintenance

In order to maintain the routing tables and minimize control overhead, each RT entry will have an Expiration Time field that will control the period of validity of the record. Every time a node sends (if it is the source node) or receives (in all other cases) a data packet, the expiration time of the corresponding RT entry is reset. In the event that the timer reaches zero and no data packet has being sent or received according to the case, the Entry Status of the record is set to Inactive. If a source node S needs to reuse a route whose status has been set to Inactive (i.e. to reactivate a route), it sends an Activate Route (ACTR) message towards the destination node D through the route, and intermediate nodes belonging to the path will forward the ACTR to the next hop until it reaches D. Upon reception of the ACTR message, the destination node changes the status of the corresponding RT entry to Active, and replies to the source node with an Activation OK message (ACTOK) again following the route. However this time, before forwarding the packet, the intermediate nodes will switch the RT entry to Active. Once the ACTOK message reaches the source node S, it also changes the status to Active and starts sending data packets. Since it is always possible that the activation of a route fails, when launching an activation process, the sender sets a time out. If by the end of this time out no ACTOK message is received, the node assumes that the route is broken and triggers a Route Discovery process using the limited flooding scenario.

4. Experimental Results

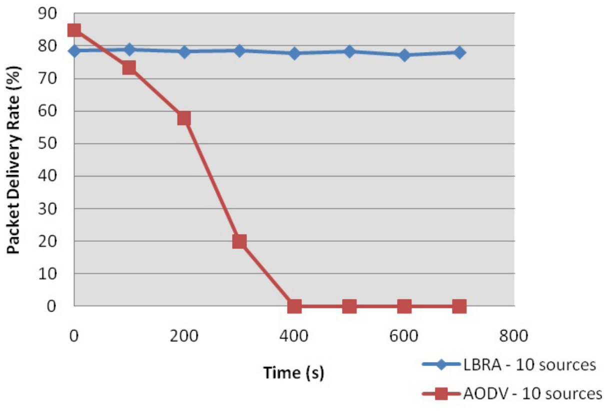
To assess the performance characteristics of our LBRA protocol, we develop a detailed simulation model using the NS2 simulation tool. We conduct these simulations with the aim of finding the advantages of the protocol LBRA with other routing protocols. As we have mentioned previously, the popular standard for WSN applications is the ZigBee specification. The network layer of ZigBee supports AODV routing. So we compare the performance of LBRA and AODV using NS2. We use the simulation parameters shown in Table 3.

The *Packet Delivery Rate* is defined as the total number of packets successfully received divided by the total number of packets sent. In this experiment we compare four scenarios, changing the number of source nodes sending data packets and we assess the Packet Delivery Rate (PDR) in each scenario. Figure 3 shows PDRs achieved using LBRA and AODV in the four scenarios. As it can be seen, regardless of the number of sources LBRA outperforms AODV, improving its performance as the traffic load increases because the "cone"' zone used to flood the RREQ packets reduced the routing overhead, which in turn reduced the burden on the MAC layer. Under high traffic load conditions (i.e. scenarios with 18 and 32 sources) LBRA

Table 3. Parameters used in simulation

Parameter	Value
Area	500 x 500 square meters
MAC Protocol	IEEE 802.15.4
Radio Propagation model	Two-ray ground reflection model
Antenna Model	Directional Antenna
Transmission Range	40 Meters
Traffic type	Constant Bit Rate (CBR)
Packet Size	32 Bytes
Data Interval	200 ms
Topology	Random with the sink at the center
Number of nodes	50 static homogeneous nodes
Number of sources	5, 10, 18 and 32 independent sources
Simulation time	800 s

keeps and average packet delivery rate of 92%, while under low traffic load conditions (scenarios with 5 and 10 sources) the packet delivery rate is 59% and 78% respectively. The reason for that is due to the number of active nodes participating in the routing process.



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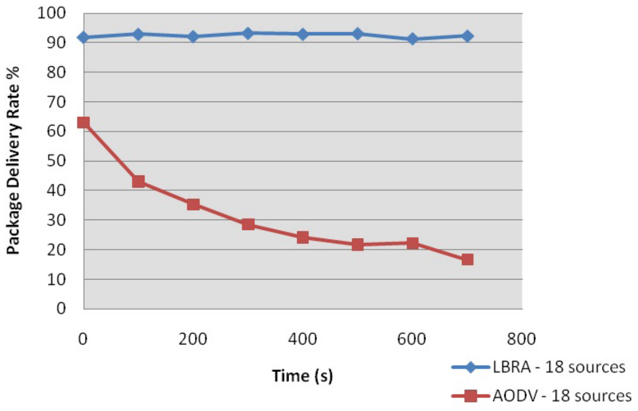
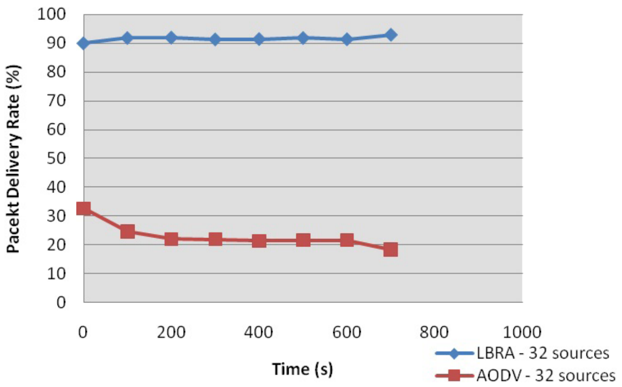
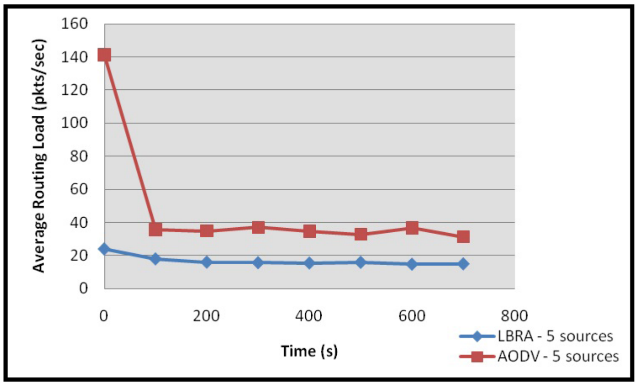


(b)



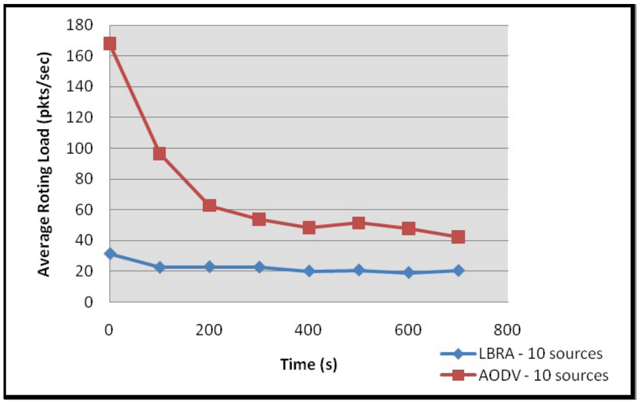
(c)



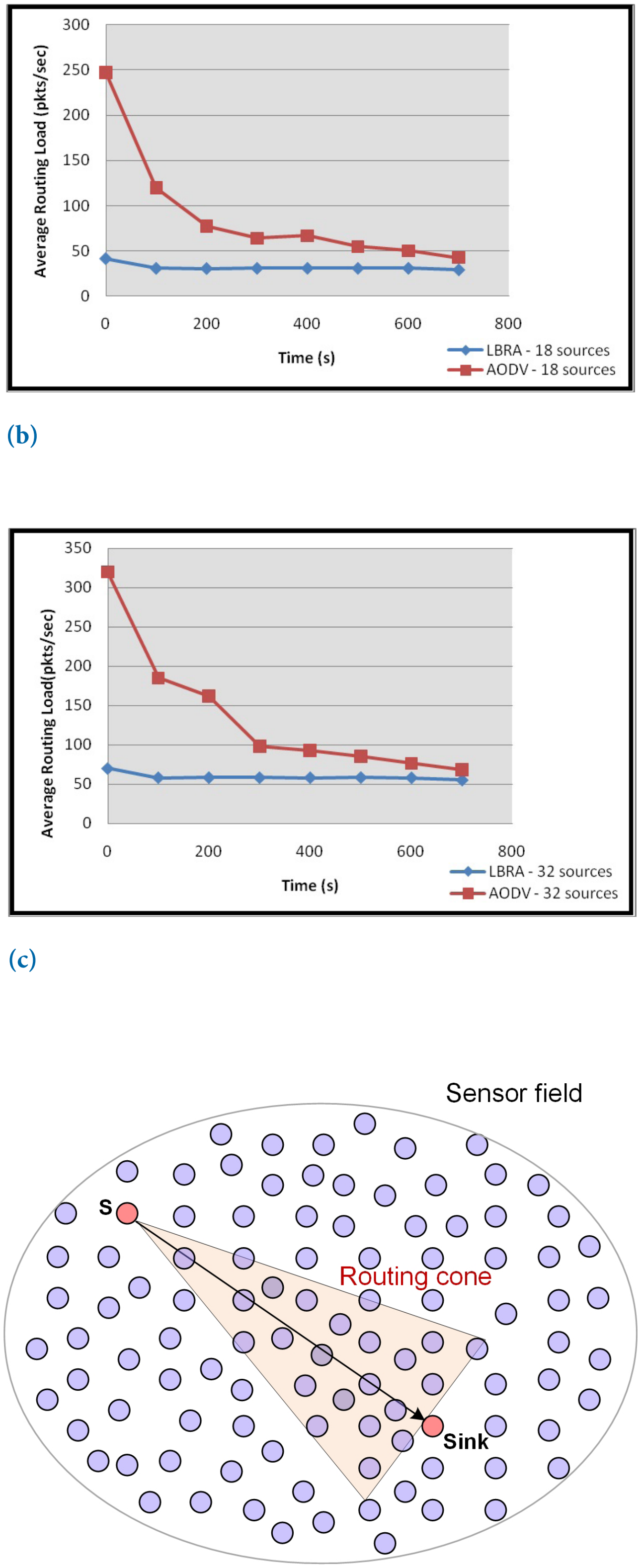
(d)

Figure 3. Average packet delivery rate comparison.

The *Average Routing Overhead* is the average ratio of routing command packets circulating in the network versusthe total of packets. This metric reflects how much band width is occupied by the routing command packets. It is clear from Figure 4 that LBRA's performance is superior to that of AODV, confirming that the latter generates more control load (i.e. generates a bigger amount of control packets). The average routing load for LBRA is 33 packets per second, while for AODV is 86. Additionally, it is evident from results that the network establishment takes considerably more time for AODV than for LBRA. The overhead is reduced by LBRA because of the utilization of an inferior number of nodes in order to find a route.



(a)



(b)

(c)

(d)

Figure 4. Average routing overhead comparison.

5. Conclusion

In this work we have proposed the Location Based Routing Algorithm (LBRA) as an alternative for WSNs routing, whose main purpose is to eliminate network control overhead as much as possible. LBRA is a novel protocol that employs smart antennas to position sensor nodes, uses local position for route decision, implements an original mechanism to collect and synchronize location information and uses node battery information to make power aware routing decisions. In order to asses to what extent LBRA truly represents an improvement with respect to the ZigBee routing, a series of simulations were designed with the help of the Network Simulator (*ns*). Basically, both protocols were implemented in the simulator and its performance was compared in a variety of traffic load, network size and mobility conditions. The experiment results showed that LBRA succeed in reducing the routing overhead and incrementing the packet delivery rate, improving the packet delivery rate for both static and mobile networks. Additionally, network power depletion is more balanced, since routing decisions are made depending on nodes' battery level. As future work we plan to consider to assess other routing parameters, for example, the mobility of the nodes, the energy spent in the routing process and the impact of node's mobility in the protocol.

6. References

1. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. Wireless sensor networks: a survey. Computer Networks. 2002; 38(4):393–422.
2. Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. Ad Hoc Networks. 2005; 3(3):325–49.
3. A scalable location service for geographic ad hoc routing. In: Li J, Jannotti J, Couto DSJD, Karger DR, Morris R, editors. Proceedings of the 6th annual international conference on Mobile computing and networking MobiCom '00. Boston, MA, United States: ACM; 2000.
4. Barontib P, Pillaia P, Chooka VWC, Chessab S, Gottab A, Hu YF. Wireless Sensor Networks: A Survey on the State of the Art and the 802.15.4 and ZigBee Standards. Computer Communications. 2007; 30(7):1655–95.
5. A survey on location services for position-based routing in mobile Ad Hoc Networks. In: Amar E, Boumerdassi S, editors. Proceedings of International Conference on Wireless Networks; Las Vegas, Nevada, USA: CSREA Press; 2007 Jun.

6. Khedr AM, Osamy W. A topology discovery algorithm for sensor network using smart antennas. Computer Communications. 2006; 29(12):2261–8.
7. Sensor network localization via received signal strength measurements with directional antennas. In: Ash JN, Potter LC, editors. Proceedings of the 2004 Allerton Conference on Communication, Control, and Computing; Monticello, Illinois, USA: 2004 Sep.
8. Efficient delivery of information in sensor networks using smart antennas. In: Dimitriou T, Kalis A, editors. ALGOSENSORS. Springer; 2004.
9. Jin Z, Jian-Ping Y, Si-Wang Z, Ya-Ping L, Guang L. A survey on position-based routing algorithms in Wireless Sensor Networks. Algorithms. 2009; 2(1):158–82.
10. Stojmenovic I. Position-based routing in ad hoc networks. IEEE Communications Magazine. 2002; 40(7):128–34.
11. Madani SA, Weber D, Mahlknecht S. Position-based routing protocol for low power wireless sensor networks. Journal of Universal Computer Science. 2010; 16(9):1215–33.
12. A novel forwarding paradigm for position-based routing (with implicit addressing). In: Fussler H, Widmer J, Mauve M, Hartenstein H, editors. Proceedings of IEEE 18th Annual Workshop on Computer Communications; Dana Point, California, USA: 2003 Oct.
13. GPSR: greedy perimeter stateless routing for wireless networks. In: Karp B, Kung HT, editors. Proceedings of the 6th Annual International Conference on Mobile Computing and Networking, MOBICOM; New York, NY, USA: ACM; 2000 Aug.
14. Locating and bypassing routing holes in sensor networks. In: Fang Q, Gao J, Guibas LJ, editors. IEEE INFOCOM 2004 - Conference on Computer Communications - Twenty-Third Annual Joint Conference of the IEEE Computer and Communications Societies; Hongkong, China; 2004 Mar.
15. Smart Sensor DVB: sensor network development boards with smart antennas. In: Leang D, Kalis A, editors. International Conference on Communications, Circuits and Systems, ICCCAS; Chengdu, China: 2004 Jun.
16. Kalis A, Antonakopoulos T. Direction finding in IEEE802.11 wireless networks. IEEE Transactions on Instrumentation and Measurement. 2002; 51(5):940–8.
17. Skiani ED, Mitilineos SA, Thomopoulos SCA. A study of the performance of wireless sensor networks operating with smart antennas. IEEE Antennas and Propagation Magazine. 2012; 54(3):50–67.
18. On the integration of smart antennas in Wireless Sensor Networks. In: Benedetti M, Rocca P, Donelli M, Lizzi L, Viani F, Martinelli M, et al., editors. IEEE Antennas and propagation society international symposium; San Diego, California, USA: 2008 Jul.
19. Kucuk K, Kavak A. Scalable location estimation using smart antennas in wireless sensor networks. Ad Hoc Networks. 2010; 8:889–903.
20. Quintero A, Li DY, Castro H. A location routing protocol based on smart antennas for ad hoc networks. Journal of Network and Computer Applications. 2007; 30(2):614–36.
21. Ko Y-B, Vaidya NH. Location-Aided Routing (LAR) in mobile ad hoc networks. Wireless Networks. 2000; 6(4):307–21.
22. AODVjr routing protocol with multiple feedback policy for ZigBee network. In: Tao S, Wei W, Xu-Dong L, Jian-Wei L, editors. IEEE 13th International Symposium on Consumer Electronics ISCE ‘09; Kyoto, Japan: 2009 May.
23. Cohen FS, de Oliveira JC, Taslidere E. Locating hot nodes and data routing for efficient decision fusion in sensor networks. Ad Hoc Networks. 2006; 4(3):416–30.
24. Energy-efficient communication protocol for wireless microsensor networks. In: Heinzelman WR, Chandrakasan A, Balakrishnan H, editors. Proceedings of the 33rd Hawaii International Conference on System Sciences; Washington, DC, USA: IEEE Computer Society; 2000 Jan.