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Geographic Adaptive Protocol for Improving the Link-Stability and Energy Efficiency in Distributed Wireless Networks

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Abstract

Energy awareness for computation and protocol management is becoming a crucial factor in the design of protocols and algorithms. On the other hand, in order to support node mobility, scalable routing strategies have been designed and these protocols try to consider the path duration in order to respect some QoS constraints and to reduce the route discovery procedures. Often energy saving and path duration and stability can be two contrasting efforts and trying to satisfy both of them can be very difficult. In this paper, a novel routing strategy is proposed. Location based routing protocols are the kinds of routing protocols, which use of nodes' location information, instead of links' information for routing. They are also known as position based routing. In position based routing protocols, it is supposed that the packet source node has position information of itself and its neighbors and packet destination node. In recent years, many location based routing protocols have been developed for ad hoc and sensor networks. In this paper we shall present the concept of location-based routing protocol, its advantages and disadvantages. We shall also look into two popular location-based protocols: Geographic Adaptive Fidelity (GAF) and Geographic and Energy Aware Routing (GEAR).. In cooperative protocol, location based routing protocol is implemented which make use of nodes' location information, instead of links' information for routing. They are also known as position based routing. This algorithm makes use of nodes which are not active into sleeping state over a period of time. Thus making cooperative network more energy efficient and implemented using Geographic Adaptive Fidelity (GAF)algorithm.

Keywords: Link Stability

Introduction

In wireless sensor networks, building efficient and scalable protocols is a very challenging task due to the limited resources and the high scale and dynamics. Using location information to help routing is often proposed as a means to achieve scalability in large mobile ad-hoc networks. These location based routing protocols are also referred to as geographic routing protocols as the sensor nodes are addressed by means of their locations instead of the formation that they carry. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. In these protocols, the state required to be maintained is minimum and their overhead is low, in addition to their fast response to dynamics. Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. The location of nodes may be available directly by communicating with a satellite, using GPS (Global Positioning System), if nodes are equipped with a small low power GPS receiver. These protocols select the next-hop towards the destination based on the known position of the neighbors and the destination. The position of the destination may denote the centroid of a region or the exact position of a specific node. Location-based routing protocols can avoid the communication overhead caused by flooding, but the calculation of the positions of neighbors may result extra overhead. To save energy, some location based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping

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nodes in the network as possible. The local minimum problem is also common for all decentralized location-based routing protocols: it might happen that all neighbors of an intermediate node are farther from the destination than the node itself. In order to circumvent this problem, every protocol uses different routing techniques. In the following sections of this paper we shall deal with two popular location based protocols: Geographic Adaptive Fidelity (GAF) and Geographic and Energy Aware Routing (GEAR).

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions. The development of such networks was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many civilian application areas, including environment and habitat monitoring, Health care applications, home automation, and traffic control . As depicted in Fig. 1, data collected by sensors is transmitted to a special node equipped with higher energy and processing capabilities called ―Base Station‖ (BS) or ―sink‖. The BS collects filters and aggregates data sent by sensors in order to extract useful information. WSNs have the potential to become the dominant sensing technology in many civilian and military applications, such as intrusion detection, environmental monitoring, object tracking, traffic control, and inventory management. In many of these applications, WSNs need to monitor the target field for detecting events of interest, e.g., the entrance of an intruder in intrusion detection applications. Widespread deployment of WSNs in target field monitoring is being deterred by the energy consumed in the monitoring process. In wireless sensor networks, nodes have limited energy resources and, consequently, protocols designed for sensor networks should be energy efficient. One recent technology that allows energy saving is cooperative transmission. In cooperative transmission, multiple nodes simultaneously receive, decode and retransmit data packets. In the model of cooperative transmission, every node on the path from the source node to the destination node becomes a cluster head, with the task of recruiting other nodes in its neighborhood and coordinating their transmissions. Consequently, the classical route from a source node to a sink node is replaced with a multi hop cooperative path, and the classical point-to-point communication is replaced with many-to-many cooperative communication. The path can then be described as ―having a width,‖ where the ―width‖ of a path at a particular hop is determined by the number of nodes on each end of a hop. For the**.** the width of each intermediate hop is 3. Of course, this ―width‖ does not need to be uniform along a path. Each hop on this path represents communication from many geographically close nodes, called a sending cluster, to another cluster of nodes, termed a receiving cluster. The nodes in each cluster cooperate in transmission of packets, which propagate along the path from one cluster to the next. The model of cooperative transmission for a single hop is further depicted. Every node in the receiving cluster receives from every node in the sending cluster. Sending nodes are synchronized, and the power level of the received signal at a receiving node is the sum of all the signal powers coming from all the sender nodes. This reduces the likelihood of a packet being received in error.

The cooperative transmission protocol consists of two phases. In the routing phase, the initial path between the source and the sink nodes is discovered as an underlying ―one-node-thick‖ path. Then, the path undergoes a thickening process in the ―recruiting-and-transmitting‖ phase. In this phase, the nodes on the initial path become cluster heads which recruit additional adjacent nodes from their neighbourhood. Recruiting is done dynamically and per packet as the packet traverses the path. When a packet is received by a cluster head of the receiving cluster, the cluster head initiates the recruiting by the next node on the ―one-node-thick‖ path. Once this recruiting is completed and the receiving cluster is established, the packet is transmitted from the sending cluster to the newly established receiving cluster. During the routing phase where the ―one-node-thick‖ path is discovered, information about the energy required for transmission to neighbouring nodes is computed. This informationis then used for cluster establishment in the ―recruiting-and-transmitting‖ phase by selecting nodes with lowest energy cost. Medium access control is done in the ―recruiting-and- transmitting‖ phase through exchanges of short control packets between the nodes on the ―one-node-thick‖ path and their neighbour nodes.

Routing in ad hoc and sensor networks is a challenging task due to the high dynamics and limited resources. There has been a large amount of non-geographic ad hoc routing protocols proposed in the literature that are either proactive (maintain routes continuously), reactive (create routes on demand) Non geographic routing protocols suffer from a huge amount of overhead for route setup and maintenance due to the frequent topology changes and they typically depend on flooding for route discovery or link state updates, which limit their scalability and efficiency. On the other hand, geographic routing protocols require only local information and thus are very efficient in wireless networks. First, nodes need to know only the location information of their direct neighbours in order to forward packets and hence the state stored is least. Second, such protocols conserve energy and bandwidth since discovery floods and state propagation are not required beyond a single hop. Third, in mobile networks with frequent topology changes, geographic routing has fast response and can find new routes quickly by using only local topology information. A key advantage of cooperative transmission is the increase of the received power at the receiving nodes. This decreases the probability of bit error and of packet loss. Alternatively, the sender nodes can use smaller transmission power for the same probability of bit error, thus reducing the energy consumption.

Energy and Resource

Energy is an important resource that needs to be preserved in order to extend the lifetime of the network ; on the other hand, the link and path stability among nodes allows the reduction of control overhead and can offer some benefits also in terms of energy saving over ad hoc networks , However, as will be shown in this contribution, the selection of more stable routes under nodes mobility can lead to the selection of shorter routes. This is not always suitable in terms of energy consumption. On the other hand, sometimes, trying to optimize the energy can lead to the selection of more fragile routes. Thus, it is evident that both the aforementioned parameters (i.e., link stability associated with the nodes mobility and energy consumption) should be considered in designing routing protocols, which allow right tradeoff between route stability and minimum energy consumption to be achieved . The main aim of this work is to propose an optimization routing model within a MANET. The model attempts to minimize simultaneously the energy consumption of the mobile nodes and maximize the link stability of the transmissions, when choosing paths for individual transmissions. The idea of considering, at the same time, energy consumption and link stability is motivated by the observation that most routing protocols tend to select shorter routes, in this way high efficiency in using wireless bandwidth and increase path stability are ensured. However, such routes may suffer from a higher energy consumption, since higher transmission ranges are needed.

Related Work

The description of some works related to the link stability, energy metrics and the respective routing protocols is given in this section. In particular, after introducing some recent contributions that separately account for path or link stability and energy consumption, a few papers on joint energy-path stability metrics are summarized and the specific contributions of this manuscript are listed.

Path Stability Aware Metrics and Routing Protocols

In the literature, many metrics focusing on the link or path stability have been defined. Among them, some have been based on the definition of the route breakage probability and some others on the link duration distribution. However,most of them have considered some parameters associated with the specific mobility model in order to estimate the stability metric. In the authors make use of statistical prediction based on the node movement. In this approach, a link stability probability has been defined on the basis of the random mobility model. A formal model to predict the lifetime of a routing path, based on the random walk mobility and on the prediction technique, was proposed . It considers a probability model derived through the subdivision into cells of the area where mobile nodes move and on the observations of node movements in these cells. Transition probabilities are calculated and a state-based model of the movement among the cells is considered. Each connection between a mobile node in a cell and the other mobile nodes among its neighbor cells is considered as the state of the wireless link. In this way, the wireless link dynamic is determined between a mobile node and its neighbors, permitting the calculation of the link lifetime. After this, through the assumption of independent link failure, the route breakage probability is derived

Energy Aware Metrics and Routing Protocols

Many contributions concerning energy consumption have been proposed in the literature. In this section, the focus is on the network layer because it is interesting to show some recent papers on energy aware routing protocols and on energy-based metrics. Moreover, some additional metrics have tried to consider also the battery life cycle , or the energy drain rate . In the following, after briefly describing some energy related metrics, energy aware routing protocols paradigms are also summarized.

Minimum Drain Rate (MDR) Cost

Energy saving mechanisms based only on metrics related to the remaining energy cannot be used to establish the best route between source and destination nodes. If a node is willing to accept all route requests only because it currently has enough residual battery capacity, much traffic load will be injected through that node. In this sense, the actual drain rate of energy consumption of the node will tend to be high, resulting in a sharp reduction of battery energy.

Energy-Based Routing Protocols

In addition to energy aware metrics such as those described in the previous section, also routing strategies and different state info management through routing protocols have been proposed in the literature. In , a distributed power control has been designed as a way to improve the energy efficiency of routing algorithms in ad hoc networks. Each node in the network estimates the power necessary to reach its own neighbors, and this power estimate is used for tuning the transmission power (thereby reducing interference and energy consumption). In , an energy efficient Optimization Link State Routing was proposed. This approach is based on the proactive info management and on the selection of Multipoint Relay (MPR) based on energy metrics, such as MMBCR and MDR.In , the authors proposed an on-demand protocol based on the MDR metric and using a route discovery mechanism and route maintenance, similar to Dynamic Source Routing (DSR)

Link Stability and Energy Aware Routing Protocols

There are few multiple metrics aware routing protocols, over distributed wireless systems, in the literature. However,in the context of novel distributed wireless systems and multimedia applications, where the system complexity is increasing, the chance of controlling and evaluating more network parameters becomes an important issue. In this context, the use of multiobjective formulation and multiple metrics plays a crucial role. To the best of our knowledge, only two published works consider simultaneously link stability and energy consumption for path selection, which is the focus of this study Specifically, a routing protocol called Power Efficient Reliable Routing protocol for mobile Ad hoc networks was proposed . This algorithm applies the following three metrics for path selection:

1) the estimated total energy to transmit and process a data packet;

2) the residual energy;

3) the path stability. Route maintenance and route discovery procedures are similar to the DSR protocol, but with the route selection based on the three aforementioned metrics.

Proposed System

We proposed the use of geographic information while disseminating queries to appropriate regions since data queries often include geographic attributes. The protocol, called Geographic Adaptive Fidelity, uses energy aware and geographically-informed neighbor selection heuristics to route a packet towards the destination region to improve the link stability during data transfer. The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. By doing this, Geographic Adaptive Fidelity can conserve more energy than directed diffusion , Each node keeps an estimated cost and a learning cost of reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbor to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted. The process of forwarding a packet to all the nodes in the target region consists of two phases:

1. Forwarding the packets towards the target region:

Upon receiving a packet, a node checks its neighbors to see if there is one neighbor, which is closer to the target region than itself. If there is more than one, the nearest neighbor to the target region is selected as the next hop. If they are all further than the node itself, this means there is a hole. In this case, one of the neighbors is picked to forward the packet based on the learning cost function. This choice can then be updated according to the convergence of the learned cost during the delivery of packets.

2. Forwarding the packets within the region:

If the packet has reached the region, it can be diffused in that region by either recursive geographic forwarding or restricted flooding. Restricted flooding is good when the sensors are not densely deployed. In high density networks, recursive geographic flooding is more energy efficient than restricted flooding. In that case, the region is divided into four sub regions and four copies of the packet are created. This splitting and forwarding process continues until the regions with only one node are left.

Algorithm/Protocol

Geographic Adaptive Fidelity or GAF is an energyaware location-based routing algorithm designed primarily for mobile ad hoc networks, but is used in sensor networks as well. This protocol aims at optimizing the performance of wireless sensor networks by identifying equivalent nodes with respect to forwarding packets. In GAF protocol, each node uses location information based on GPS to associate itself with a "*virtual grid*" so that the entire area is divided into several square grids, and the node with the highest residual energy within each grid becomes the master of the grid. Two nodes are considered to be equivalent when they maintain the same set of neighbor nodes and so they can belong to the same communication routes. Source and destination in the application are excluded from this characterization.

Nodes use their GPS-indicated location to associate itself with a point in the virtual grid. Inside each zone, nodes collaborate with each other to play different roles. For example, nodes will elect one sensor node to stay awake for a certain period of time and then they go to sleep. This node is responsible for monitoring and reporting data to the sink on behalf of the nodes in the zone and is known as the master node. Other nodes in the same grid can be regarded as redundant with respect to forwarding packets, and thus they can be safely put to sleep without sacrificing the "*routing fidelity*" (or routing efficiency). The slave nodes switch between off and listening with the guarantee that one master node in each grid will stay awake to route packets. For example, nodes 2, 3 and 4 in the virtual grid B in Fig 2 are equivalent in the sense that one of them can forward packets between nodes 1 and 5 while the other two can sleep to conserve energy. Hence, GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. The grid size r can be easily deduced from the relationship between r and the radio range R which is given by the formula:

$$r \leq R/\sqrt{5}$$

There are three states defined in GAF. These states are discovery, for determining the neighbors in the grid, active reflecting participation in routing and sleep when the radio is turned off. In order to handle the mobility, each node in the grid estimates it's leaving time of grid and sends this to its neighbors. The sleeping neighbors adjust their sleeping time accordingly in order to keep the routing fidelity. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active.

Experimental Studies

Implementation Details

1. A multi objective mathematical formulation for the joint stability and energy problem is presented.
2. The proposed protocol is based on a geographic paradigm, different by other routing protocols accounting for joint metrics, such as PERRA.
3. Adoption of a novel stability metric based on the residual link lifetime concept. This metric is considered more robust than the metric proposed because it is independent on the transmission radius and node speed parameters that can be affected by measurement errors.
4. A novel energy aware-metric, adopted in our previous contributions, has been introduced in the proposed optimization model in order to consider not only the residual energy but also its time variation associated with the traffic load.
5. The multi-objective routing algorithm is integrated in the scalable routing protocol

Simulation details are:

- . Data packet delivery ratio: it is the number of packets received at destination on data packets sent by source.
- . Protocol overhead: it is calculated as the number of HELLO packets sent in the LAER and GPSRprotocols and the number of RREQ, RREP, and RERR in the PERRA protocol.
- To have detailed energy-related information over a simulation, the ns-2 code was modified to obtain the amount of energy consumed (energy spent in transmitting, receiving) over time. In this way, accurate information was obtained about energy at every simulation time.
- We used these data to evaluate the protocols from the energetic point of view.
- Simulation output variables considered in the evaluation of the energy and link stability metrics are the following Average link stability: this parameter is adopted rather than path stability because for protocols such as GPSR, E-GPSR, and LAER the path stability cannot be considered due to the absence of a path establishment phase;
- . Average energy consumption: this parameter allows to make considerations about energy wastage associated with the route maintenance and route discovery and it accounts for energy consumption during transmission and reception of control and data packets;
- . Average node residual energy: it can be useful to evaluate the remaining energy in order to have an idea of the network lifetime;
- . Variance of node residual energy: this parameter is considered to evaluate the distribution of energy among nodes. The greater is the dispersion around the average residual node energy, the higher is the

unfairness in the node usage and in the energy dissipation among nodes.

- parameters adopted in the performance evaluation campaigns are listed in the common parameters adopted in the simulator regardless the specific considered protocols.

Modules

Link-Stability Aware Metric

In this paper, differently , a link stability metric rather than a path stability metric is considered. This is due to the protocol scalability properties that we tried to offer to the routing scheme. As will be shown in next sections, a node with the best tradeoff between link stability and energy consumption is adopted through a local forwarding criterion. Before explaining the method adopted to estimate the link stability grade, the definition of link stability is provided

Energy-Aware Metric

In this study, it is assumed that each wireless node has the capability of forwarding an incoming packet to one of its neighboring nodes and to receive information from a transmitting node. In addition, each node is able to identify all its neighbors through protocol messages. It is assumed that each node does not enter in standby mode and each node can overhear the packet inside its transmission range and it is not addressed to itself.

Forwarding Strategy

The data forwarding strategy of LAER is based on a greedy technique such as GPSR. However, differently by GPSR, the next hop selection tries to minimize the joint energy stability metric. LAER packet forwarding presents high scalability property because only the neighborhood and destination knowledge are necessary for the greedy technique. The flexibility of energy-stability-based greedy forwarding is offered through the capability to weight the stability and the energy consumption on the basis of the interest of the application layer. This means that if an application is more sensitive to the path stability..

Local Maximum Recovery Strategy

During the greedy technique, it is possible to meet a void or local maximum in the GPSR. Local maximum representsa point in the network where it is not possible to find any neighbor node that leads to the minimization of the distance toward the destination in comparison with the current node. In this case, the protocol assumes to use a recovery mode called Perimeter Forwarding.

Packet Format Analysis

Concerning the data packets and HELLO packets adopted by LAER, it is necessary a packet modification and extension because we need to update the info related to energy index and stability index of neighbor nodes and because also the weights p1 and p2 can be determined by application layer on the basis of the importance given to the energy consumption or to link stability. For this reason, a modified version of HELLO and DATA packet formats was adopted such as presented below. The data packet format, instead, In this case also the weights info is carried by data packets. It is observed that Lp is important to establish when to switch from perimeter to greedy mode. When, in the perimeter mode, a node with distance from destination lower than Lp is reached, it is possible to switch in greedy forwarding. Concerning e0, it represents that location of the first edge on the new face of the polygon traversed.

Results and Discussion

From proposed the use of geographic information while disseminating queries to appropriate regions since data queries often include geographic attributes. The protocol, called Geographic and Energy Aware Routing (GEAR), uses energy aware and geographically-informed neighbor selection heuristics to route a packet towards the destination region. The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. By doing this, GEAR can conserve more energy than directed diffusion. In GEAR, each node keeps an estimated cost and a learning cost of reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbor to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted. The process of forwarding a packet to all the nodes in the target region consists of two phases:

1. Forwarding the packets towards the target region: Upon receiving a packet, a node checks its neighbors to see if there is one neighbor, which is closer to the target region than itself. If there is more than one, the nearest neighbor to the target region is selected as the next hop. If they are all further than the node itself, this means there is a hole. In this case, one of the neighbors is picked to forward the packet based on the learning cost function. This choice can then be

updated according to the convergence of the learned cost during the delivery of packets.

2. Forwarding the packets within the region: If the packet has reached the region, it can be diffused in that region by either recursive geographic forwarding or restricted flooding. Restricted flooding is good when the sensors are not densely deployed. In high density networks, recursive geographic flooding is more energy efficient than restricted flooding. In that case, the region is divided into four sub regions and four copies of the packet are created. This splitting and forwarding process continues until the regions with only one node are left. An example is depicted In , GEAR was compared to a similar non-energy-aware routing protocol GPSR , which is one of the earlier works in geographic routing that uses planar graphs to solve the problem of holes. In case of GPSR, the packets follow the perimeter of the planar graph to find their route. Although the GPSR approach reduces the number of states a node should keep, it has been designed for general mobile ad hoc networks and requires a location service to map locations and node identifiers. GEAR not only reduces energy consumption for the route setup, but also performs better than GPSR in terms of packet delivery. The simulation results show that for an uneven traffic distribution, GEAR delivers 70% to 80% more packets than GPSR. For uniform traffic pairs GEAR delivers 25%-35% more packets than GPSR. Medium Access Delay(s): is the average time spent between the time a packet is handed to the GAF layer and the time it is received at the next hop. This delay accounts for the contention delay in the case of contention-based protocols and scheduling delay in schedule-based protocols.

Packet Drop Rate: is the fraction of packets that is dropped during the medium access. It is calculated as the percentage of dropped packets to the total packets sent from the MAC layer throughout the simulation.

This metric shows the performance of the GAP protocol in terms of medium access overhead introduced in terms of wasted number of packets.

Good put: is the ratio between the total number of packets received at the sink and the total number of packets generated by all sensor nodes. As a result, the efficiency of the GAF protocol is investigated.

Average Energy Consumption (J): is the average GAF protocol not only conserves energy, but also minimizes unnecessary channel access contention and there by improves the packet drop rate without compromising the event detection latency. This is in contrast to the energy- latency tradeoffs that has been the main focus of many energy efficient in WSN. When the simulation done and the numerical values collected for both the existing system and the proposed system for the performance parameters 1. Energy consumed 2. Bandwidth Utilized 3. Delay 4. Packet delivery ratio 5. Number of packets sent and the result was noted down

Conclusion

This paper, evaluated the performance of cooperative transmission, where nodes in a sending cluster are synchronized to communicate a packet to nodes in a receiving cluster. In this communication model, the power of the received signal at each node of the receiving cluster is a sum of the powers of the transmitted independent signals of the nodes in the sending cluster. The increased power of the received signal, leads to overall saving in network energy and to end-to-end robustness to data loss.

Future Enhancement

The cooperative protocol is implemented using GAP algorithm to achieve more energy efficiency by using location information instead of link‘s information for outing.GAP is a hierarchical protocol, with limited power usage. As they operate on the basis of the geographic or location information for routing, data aggregation at any point is absent. Although GAP is highly scalable, it will not take care of QoS. Future direction may be conducted to enable QoS in the GAP algorithm during data submission.

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