Routing and Topology Extraction Protocol for a Wireless Sensor Network using Video Information

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Abstract: Recent technological improvements have made the deployment of small, inexpensive, low-power devices (nodes), which are capable of local processing and wireless communication, a reality. Such structure is called Wireless Sensor Network (WSN). Nowadays, a WSN node may include complex sensing devices like video cameras. This paper proposes a new routing algorithm adapted for this context.

Keywords: routing protocols, topology extraction, wireless sensor networks

1 Introduction

The wireless sensor networks are envisioned to become a powerful instrument for the near future. A standard wireless sensor network consists of a large number of small and cheap sensor nodes ranging from tens or hundreds to thousands, the communication is made in a multi-hop manner, each node being in the same time a sensor and a router. A wireless sensor network node consist of three main modules, the sensing module that collects information from the environment, the communication module that sustain wireless data communication between nodes and the processing module that processes the information provided by the sensor module or received from neighbour nodes.

The similarities between the wireless sensor networks and the mobile ad-hoc networks are quite obvious with respect to the structure, network topology and communication manner. In spite of that, there are several aspects, specific to the applications where wireless sensor networks are used, that differentiate the two. According to Krishnamachari [1] there are four main differences between wireless sensor networks and mobile ad-hoc networks. In a standard wireless sensor network there is only one gateway node, which collect the information from the entire network. In this case several nodes send data trough the existing routes in a multi-hop manner to the gateway node; communication between any pair of nodes in the network is not specific to WSN as the case of mobile ad-hoc networks where any pair of mobile devices can communicate with each other. A common application of WSN is habitat monitoring [2]. I this situations sensor nodes are spread over a large area and collect information like temperature, humidity, light intensity etc. In such a configuration, several sensors can send data to the central gateway referring to the same phenomena that happens in the field leading to some data redundancy in the network. Another aspect that makes the difference between the two types of networks is the notion of dynamics. In a standard WSN the nodes are not mobile in the sense of changing position overtime. However, in specific applications a wireless sensor network can contain some mobile sensor/robotic nodes with moving capabilities. Generally, the dynamics of a WSN involves nodes leave the network because of system failure or power depletion, but it requires network reconfiguration.

The most important characteristic of wireless sensor networks is power consumption. Because sensor nodes are deployed in large number and in remote and some times hostile environments battery changing or recharging is not a feasible operation in case of WSN in contrast with mobile ad-hoc networks where the devices can be recharged easily. In the same time a wireless sensor network is required to be operational for a long period of time ranging from month to years. The most energy-consuming module within a sensor node is the communication module. To reduce the energy consumption the duty cycle of the transceiver has to be as low as possible. One paradigm that leads to power saving in WSN is data aggregation and compression [1, 3]. In this paper we will take a different approach from the point of view of image acquisition and processing using wireless sensor networks.

This paper is organized as follows: Section II is an overview on routing protocols suitable for wireless sensor networks; Section III analyzes various topology extraction algorithms and propose a new one that is adapted for video sensors; Section IV proposes an adaptive routing solution suitable for video sensors; Section V add support for topology extraction; Section VI discuss the implementation context; Section VII depict the simulations made for validation and evaluation of the protocol. In the last section we present our conclusions and future work.

2 Adaptive Routing

This part is an overview on basic routing schemas used in ad-hoc networks like wireless sensor networks. These routing algorithms can be classified in two main categories: proactive and reactive protocols. Proactive routing protocols like Adaptive Distance Vector routing protocol, Destination Sequenced Distance Vector routing protocol (DSDV), Path-Finding Algorithms (PFA), and the Wireless Routing Protocol (WRP) after route discovery sequence preserve these routes continuously for each node in the network. Reactive routing protocols like Gafni and Bertsekas's algorithm, Dynamic Source Routing (DSR) protocol, Temporally Ordered Routing Algorithm (TORA) protocol, Associative-Based Routing (ABR) protocol, Signal Stability-Based Routing (SBR) protocol, Location Aided Routing (LAR) algorithm, Power Aware Routing protocol, Ad-hoc On-demand Distance-vector (AODV) protocol, establish routes only when communication is needed and maintain this routes for as long as he connection is needed even in case of network topology changes [4].

The Distance Vector technique (DV) is the basis for several routing algorithms including DSDV and AODV; in this technique each router has a routing table in which it stores the address of the next hop and the distance for each possible destination within the network. Each router broadcasts its table to the neighbor routers and receives tables from them to update its own routing information according to network changes. There can be both short-living and long-living routing loops in order to handle the stale information problem [5].

Distance-Vector Routing protocol (DSDV) is a destination vector based routing protocol that uses a sequence number for each routing entry in the table in order to track changes in the network. Routing table updates are made by periodically broadcast or triggered broadcast when enough changes in the network configuration occurred. DSDV protocol has several drawbacks with respect with the wireless sensor networks requirements. On one hand the global routing table stored on each node requires storage that might not be available due to resource constraints. Another drawback of DSDV is the communication overhead generated by the routing table updates that requires information transfer between network nodes.

Optimized Link State Routing (OLSR) is also a proactive routing protocol; it is an optimization of the classical link-state protocol to be suited for wireless ad-hoc networks. The flooding overhead is minimized in case of OLSR by using only selected nodes for traffic information retransmission and because only partial link information is used for flooding trough the network [6]. Each node will flood the costs of all the links that it is connected and based on this information each node can compute a path to each node using shortest path algorithms.

Next we present some reactive protocols. AODV is based on a distance vector technique such as the DSDV protocol, with the difference that the AODV is a reactive routing protocol. AODV does not maintain routes permanently in the network, but creates them when communication is needed and releases them after data are transferred. The route is found by sending a request to the neighbor nodes, in the closest neighborhood and then enlarges the circle of neighbors until the route is found or the time to search expires. After the route is found it is maintained as long as it needs. The route expires and is no longer maintained after a specified period of time if it is not used for communication.

LAR is a protocol that uses location information to find the routes for communication [7]. It uses location information to reduce the area of search for a route, reducing in this way the communication overhead. Location information is taken from GPS receivers and because of mobility of the nodes the approximate position is estimated based on time and average velocity of the node.

From the wireless sensor networks point of view, the three protocols presented have two major drawbacks: communication overhead and complex hardware components.

A good example of a data-centric routing protocol, suited for wireless sensor networks is directed diffusion. According to it, the data consumer will send a request through the network directed to the data source area of the network by flooding or geographical routing [8]. The node that receives such a request message and find itself in the poison of providing the necessary information will send the data through the path that lead the request to it. The nodes along that path that receive and forward the information from the source to its destination can process the information by compressing or aggregating the information with data received from other nodes, data that refers to the same phenomena. This in network information processing makes directed diffusion a data-centric protocol suited for wireless sensor networks.

As we mentioned before, one of the most important optimization that can be made to a routing protocol in order to fit wireless sensor networks requirements is minimizing power consumption. As presented in [9] an important factor related to power consumption is network survivability. We try to adapt these approaches in context of quite large data exchange involved by video sensors and dense WSN deployment. We split the proposed protocol into two distinct phases. The first consists in discovering and storing distributed route information and is presented in Section 4. The second focus on gathering images required in topology extraction and is discussed in Section 5.

3 Topology Extraction

Topology extraction represents a key issue in a wireless sensor networks. Most of the cases, sensor nodes are deployed in an ad hoc manner and there is no a priori knowledge of location. It is the node responsibility to identify themselves in some spatial co-ordinate system and manage communication. An easy solution is by using a GPS receiver. However, there are some strong factors against the usage of GPS. It can works only outdoors, it is expensive and not suitable in the construction of small cheap sensor nodes and it cannot work in the presence of any obstruction covering the node.

One way to solve the problem is to consider the network organized as a hierarchy, with the nodes in the upper level being more complex and already knowing their location through some sophisticated technique (commonly GPS-based). These nodes then act as beacons by transmitting their position periodically. The nodes, which have not yet inferred their position, listen to broadcasts from these beacons and use the information from beacons with low message loss to calculate its own position. This is called as *proximity based localization*. The solution has an obvious homogeneity lack.

Another solution, proposed by Shen et al., is a network architecture called SINA [10]. In this architecture sensor nodes autonomously form groups called as clusters. The process is based on power level and proximity. This clustering is applied recursively to form a hierarchy of clusters. They aim to increase the life of a sensor node by decreasing the power required for information exchange.

Other ideas are based on the time of flight of the communication signal between two adjacent nodes or on the attenuation of the radio signal strength [11, 12].

Our solution tries to combine the proximity information, like at SINA, with image information from the video sensors. The central server will receive all images taken synchronously by the nodes and augmented with proximity information. Using image registration algorithms [13] the server tries to calculate all necessary affine transformations that determine superposition of all adjacent images pairs. Based on transformation parameters, it can compute distances and angles between video camera's sensors. The work presented here refers only the protocol for collecting these images and, same time, managing energy aware adaptive routes.

4 Setup Phase

This represents the initial step after the node deployment. However, this phase could by repeated time to time to ensure configuration update. It has a dual purpose. The first is to fill the routing tables, maintained by each node, with information about proximity and hop count to the central point. The second is to query the nodes for synchronously image information used to extract topology.

The central server broadcasts a setup message containing empty route path information. Each node that receives a setup message will determine if itself is included or not in the route information. If included, it simply drops the message. It not, it refreshes its routing table from the message routing information and broadcasts the message further. Same time, it starts a timer that manage the image capturing.

Nodes are both routers and end points in the same time. Each nodes help server requests to be propagated to the entire network by forwarding the request to its neighbors. Also images that are sent to the server are routed back to the server in an energy-efficient manner that preserves network integrity. For this to happen, each node keeps simple routing information that will describe each of its neighbors by its current energy level and the hop-count until the server. To obtain energy-efficiency the current node elects the neighbor with the lowest hop-count as future node in the path. Because this may lead to premature exhaustion of some nodes that may produce network partitioning several complementary measures are used. Node energy is rated from 0 (dead) to 100 (full power). So, when node energy is lower than 20% of its initial value, the node will not participate in routing and also its neighbor will not elect it as next hop in the path back to server. In these conditions the elected node will be another node with the same or higher hop-count to the server. When node energy is over 50% there are no restrictions in electing a node as next hop. When energy node is between 20%-50% the node will be elected as next hop only if there aren't other nodes (also neighbors of the current node) with lower hop-count and energy level over 20% or nodes with equal hop-count but in the same or lower major energy level. If we have more than one candidate as possible next hop we will use LRU algorithm to impose equal energy consumption for neighbors.

5 Transferring Video Information

At server request the sensor nodes need to send back a image captured by node's camera. The server makes a single, general request available for all nodes connected inside the network. Another remark is that WSN are dense networks, having multiple connections for each sensor node. In these conditions, a request from server will be received by a node possibility multiple times. In order to avoid sending the image more than once for each of server's requests, we augmented each request with an unique id.

The message containing node's response will be sent back to the server using the most energy-efficient path with network integrity preservation. Indeed, the most energy-efficient path is considered the path with the lowest hop-count to server. Using routing information existent in each node, next possible hop in the message path will be elected using the following rules:

- the best alternative is to use a as next hop the neighbor with the lowest hop-count to server and energy-level of the node is altering this behavior if the rate is under 20%, because the node is not involved in message routing to preserve energy for its own purpose (and this avoids also network partitioning).

- if more than one nodes are eligible (they have the same hop-count to server and same major energy level) than LRU algorithm will be used to prevent premature exhaust of a node (and a possible premature network partitioning).

Collision avoidance is not covered at this stage. The issue of collision avoidance is far more important in this stage than the previous stage because the size of message send back to server as response is much higher because it contains the captured image, hence collision has higher probability because transmission over radio channel takes longer (broadcast channel is used). For collision avoidance can be used an algorithm that will impose a back-off timer for each node. The back-off timer is composed by two components: a static component and a dynamic one. The static component increases according to the time spent by server request to arrive to node (or hop-count). The dynamic component is just a random time that will allow nodes inside the same level (with the same hop-count) to avoid collision. The static component assures that collisions are avoided between nodes from different levels also.

6 Simulation Environment

The protocol was implemented in OMNeT++, a viable discrete event simulation framework. It is designed for studying both the networking aspects and the distributed computing aspects of sensor networks as concluded in [14] using a comparison against *ns2* simulator for Directed Diffusion protocol implementations, a well known protocol for sensor networks.

OMNeT++ offers a discrete event simulation framework, a platform that could be used for modeling and simulating a variety of systems. **O**bjective **M**odular **N**etwork Test-bed in C++ (OMNeT++) is a component-based, modular simulation framework. Its model is a collection of hierarchically nested modules. The top-level module is also called the System Module or Network. This module contains one or more sub-modules each of which could contain other sub-modules. The modules can be nested to any depth and hence it is possible to capture complex system models. Modules are distinguished as being either simple or compound. A simple module is associated with a C++ file that supplies the desired behaviors that encapsulate algorithms. Compound modules are aggregates of simple modules and are not directly associated with a C++ file that supplies behaviors. Modules communicate by exchanging messages (messages may represent frames or packets in a computer network). The local simulation time advances when a module receives messages from another module or from itself. A module is using self-messages to schedule events at a later time. The structure and interface of the modules are specified using a network description language. Simulation executions are easily configured via initialization files. It tracks the events generated and ensures that messages are delivered to the right modules at the right time. OMNeT++ offers an extensive simulation library that includes support for input/output, statistics and data collection, graphical presentation of simulation data, random number generators and data structures.

In order to easily generate NED files (which contain network structure description) we use a generator that uses simple XML files containing network topology. It includes, in a compact form, server description, sensor nodes description and channel implementation for wireless broadcast. The output is a NED file that can be used with the rest of the definitions and implementation to perform an OMNeT++ simulation. The main reason for using this tool is that the NED file needs to contain large amount of data, which needs to be synchronized when representing very dense networks with large number of nodes and significant number of broadband channels such as wireless sensor networks.

The simulation executes the main module (the wireless sensor network) composed by: a server, which is the sink where all captured pictures are sent, nodes that represents sensor nodes deployed and channels that represent the physical radio connections between server and nodes or between different nodes.

The protocol uses broadcast communication to achieve interaction inside the network. The broadcast channel is implemented using channels that connect only two entities. The implication of this decision is that server or sensor nodes are connected to a number of channels that is equal to its number of neighbors. As a consequence of this design each message received by a sensor node is cloned for each of its associated channels (or neighbors), the information of message is updated and then send to each neighbors a copy to allow correct propagation of the messages.

The message used in the model can carry the following information: the type of message (server request or node response), the hop-count from/to the server depending of the message type, the network path followed by this message, an unique id in case the message is server request to allow nodes the possibility to detect if the same request was already set and a bitmap representing the image captured by node’s camera when the type of message is node response.

7 Experimental Results

We present here some results from a preliminary performance evaluation of our routing algorithm. Our main goals are to compare this protocol against standard flooding schema and to understand the performance impact of node failures.

We choose three metrics to analyze the performance of proposed protocol: number of transmitted messages (NTM), total amount of received messages (NRM) and average dissipated energy (ADE).

The data set includes four different layouts consisting in one central server and 3/8/16/30 nodes as presented in Figure 1.

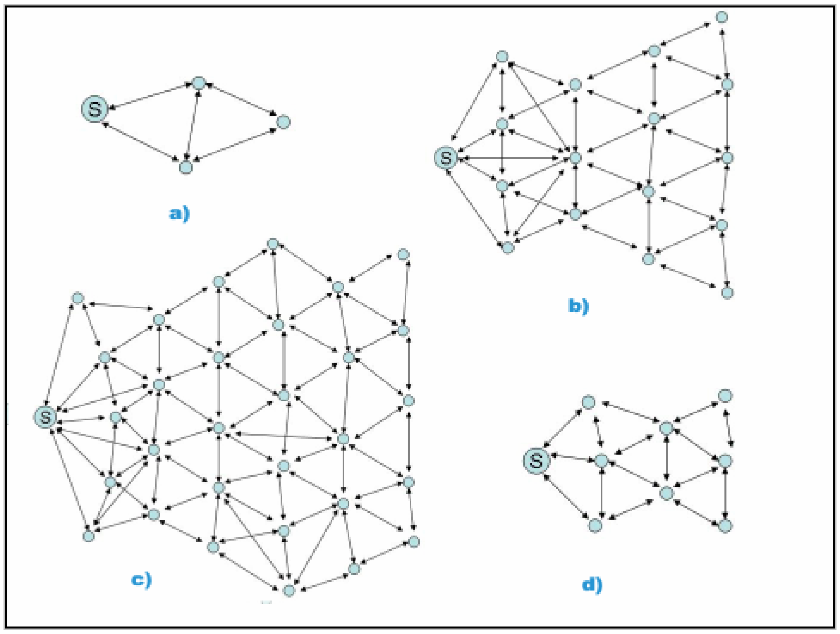

Figure 1
Samples layouts used in test: a) 3 Nodes, b) 16 Nodes, c) 30 Nodes, d) 8 Nodes

The results of simulation against flooding algorithm are presented in Figure 2. It shows the total amount of sent messages and the total amount of received messages for both flooding and our adaptive routing protocol on a logarithmic scale. Figure 3 presents the simulation result in term of average dissipated energy.

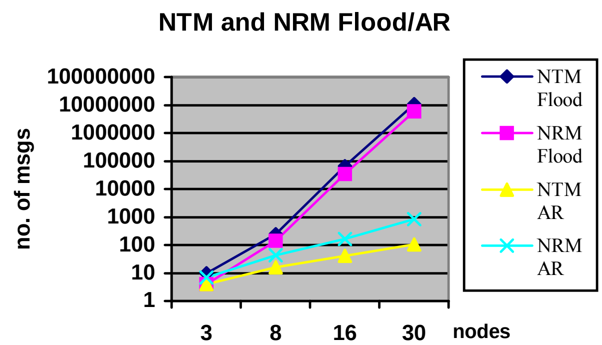

Figure 2
NTM and NRM on Flooding and Adaptive Routing on a Logarithmic Scale

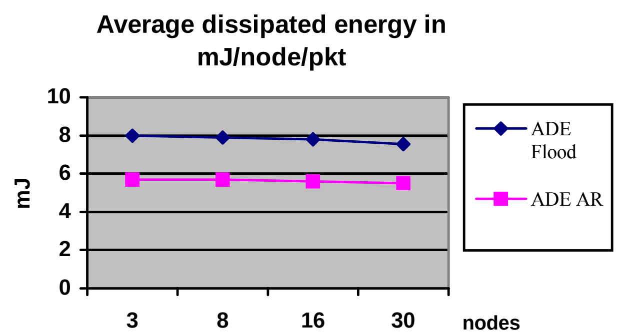

Figure 3
Estimated Average Dissipated Energy on Flooding and Adaptive Routing

Conclusions

In this paper, we presented an adaptive routing protocol for a wireless sensor network designed for low energy consumption, in context of exchanging video information. This protocol also helps a central point in collecting synchronized images for topology extraction. It has also support for network survivability by considering node energy information at the level of routing decision.

Future work will include optimization of the collision avoidance mechanism considering large video information exchange and tuning of the routing mechanisms in context of different network topologies.

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