Efficient Routing in PAN and Sensor Networks

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Abstract

Unlike wired networks, where a relative stabile topology is given and normally no fast changing routing tables exists, routing in PAN (personal area network) and sensor networks is more difficult. This can be much simplified if each node knows the current network topology. The biggest problem is to find a compromise between topicality and limited overhead in order to power limitations. In this paper we present various algorithms for ad-hoc networks and classify them to their efficiency and relevancy when applied to PAN and sensor networks.

1. Introduction

The first research project on wireless networks dated back to the seventies. It was financed by the American Department of Defense (DoD), aimed to get rid of wired infrastructure.

The most important aspects in the development have been the fact that in many regions infrastructure is not available and the establishment of such wireless networks has to be fast and self-organized.

Another important issue is the physical range limitation of wireless nodes, so that the nodes must be able to store and forward information which is not intended for them self.

In the last ten years there had been an enormous progress in the field of wireless networks, above all also by the area always winning at interest of the Ubiquitous Computing, because spontaneous cross-linking and rapid adaptation of network topologies play a basic role here.

Generally, there are two parts of wireless networks: the infrastructure networks, in which the bridges are wired nodes, and the other part, the ad-hoc networks, which I will discuss later in the rest of this paper.

A mobile ad-hoc network (MANET) is defined as a distributed, mobile, wireless, multi-hop network, which consists of several nodes. There are many different kinds of MANETs. However, only PAN and sensor networks will be focused in this paper.

A PAN network is a human centered network connecting personal communication devices in a short-range (less than 10 meters), “personal” or “body” space. The biggest differences between PAN and sensor networks are the number and type of the network nodes. A sensor network may consist of hundreds of simple, identical sensors/nodes, while PAN normally consists of a few intelligent, specialized devices (e.g. mobile phones, PDAs, earphones, intelligent watches).

Moreover, sensor nodes are free to move arbitrarily, thus their network topology changes rapidly. So an important issue in PAN and sensor networks is the efficient routing. The biggest problem is to find a compromise between extra and minimal overhead in order to power limitations.

Other problems are the selection of the optimal path, which can be broken-down to the selection of the optimal neighbouring (or next hop), avoiding loops, and the link failure recovery.

In this paper, we present the most important algorithms for ad-hoc networks and classify them according to their relevancy and efficiency, when applied to PAN and sensor networks.

2. Routing Algorithms Classification

Generally, depending on the way of calculating routes, routing algorithms in ad-hoc networks can be classified in two categories:

Proactive Routing algorithms: Each node calculates proactively consistent and up-to-date routing information to all nodes and stores that information in routing tables, which are periodically or on-demand exchanged between the nodes.
When the network topology changes, the nodes propagate update messages throughout the network to update the network image.

Reactive Routing algorithms: Each node calculates routing information only when data is ready to be transmitted adopting a lazy routing approach. The calculated path is considered valid as long as the destination is reachable or until the route is no longer needed.

Following this classification, we could classify the following algorithms into the first group, the proactive routing algorithms and the second group, the reactive routing algorithms.

Proactive Routing Algorithms
Destination-Sequenced Distance-Vector (DSDV)
Wireless Routing Protocol (WRP)
Fisheye State Routing (FSR)
Hierarchical State Routing (HSR)

Reactive Routing Algorithms
Signal Stability Adaptive Routing (SSR)
Temporally Ordered Routing Algorithm (TORA)
Ad Hoc On-Demand Distance Vector Routing (AODV)
Efficient Route Update Protocol (ERUP)

3. Routing Algorithms

This section give some more detailed about each algorithm.

3.1 Proactive Routing Algorithms

The Proactive Routing Algorithm maintains in each node one or more tables which contains the routing information for all other nodes in the network. So Proactive Routing Algorithms are called “table-driven” algorithms, too.

When the network topology changes, the nodes propagate update messages throughout the network to update the network image.

Proactive Algorithms always have an actually network image, but that causes extra traffic. In the following sections, a selections of the most important table-driven ad-hoc routing protocols is presented.

3.1.1 Destination-Sequenced Distance-Vector (DSDV)

The Destination-Sequenced Distance-Vector (DSDV) routing algorithm is based on Bellman-Ford Routing (distance-vector-algorithm) and maintains in each node a routing table that lists all available destinations, the number of hops in each path and a sequence number.

The node sends periodically or by changes the routing table (“full dump”) or the modified entries (“incremental update”) to the neighbouring nodes (broadcast). DSDV update packet contains an unique sequence number (SN), the transmitter assigns this SN, and the receiver selects the packet with the highest SN, in case more than one packet has the same SN, the route with best cost metric is selected.

An advantage of DSDV is that in relative stable networks like Wireless PAN, incremental updates are sent to avoid extra traffic.

Disadvantages are that in fast changing networks, like sensor networks, the number of incremental packets increase rapidly, then full dumps are preferred or DSDV requires bidirectional links to operate.

3.1.2 Wireless Routing Protocol (WRP)

The Wireless Routing Protocol (WRP) is a proactive, table-driven protocol, which maintains three tables in each node - the Distance table, the Routing table and the Link Cost table - and a Message Retransmission List.

The Distance table contains distance to any destination via every neighbouring node, the Routing table contains the predecessor and the successor nodes on the path which helps to find the shortest path. The Link Cost table contains the cost of the link to each neighbouring node.

In WRP each node has consistent knowledge of the links status towards all neighbouring nodes. In order to reach this, each node in WRP exchanges periodically or by link status changes its routing tables with their neighbours using update messages, in case of no changes in routing tables, nodes sends an idle “Hello” message.

By receiving an update message, the recipient modifies its distance table if required and checks for better paths using the new information. Then an Acknowledge message is returned to the originator which can update its own routing tables.

The Message Retransmission List contains information to let a node know which of its neighbour has not acknowledged its update message

3.1.3 Fisheye State Routing (FSR)

The Fisheye State Routing (FSR) is a proactive, table-driven algorithm which enhances the Global State Routing (GSR) algorithm which is a similar approach to DSDV. But one intention of FSR is to lower updating overheads and enable network scaling with large number of nodes.

In order to reach this, FSR sends information about the near (neighbouring) nodes more frequently than information about far nodes to reduce the update packet size. FSR organizes the neighbouring nodes in scopes, defined by the number of hops required to reach the node.

So each node in FSR has accurate routing information about neighbouring nodes. How we can see in Figure 1, the information quality decreases with each further node.

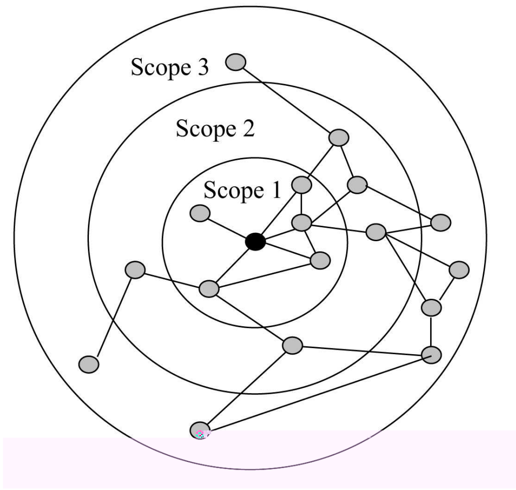


Figure 1: Precision of the information in FSR decreases to the edge

3.1.4 Hierarchical State Routing (HSR)

Hierarchical State Routing (HSR) is another proactive algorithm which partitions the network nodes into multi-layer clusters; you can see an example in Figure 2. In each cluster one node is cluster-parent and these cluster-parents are organized into a higher-level of clusters and so forth. HSR generates a tree-like hierarchy.

Some nodes belong to more than one cluster and are called gateways, each node has a network address (gateways more than one).

If routing information is modified, each node broadcasts information in their cluster. Cluster-parent forwards this information to all neighbouring cluster-parents, which forwards the information to their lower layers.

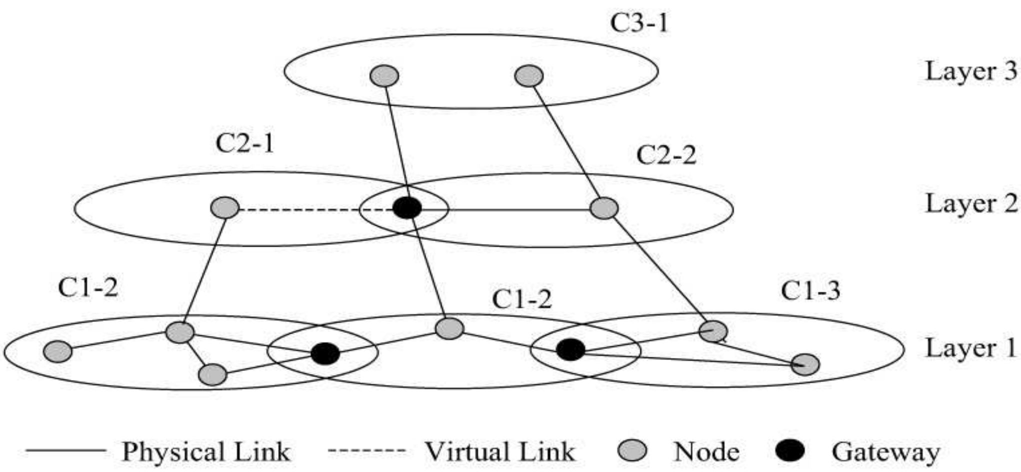


Figure 2: Example HSR topology clustering

3.2 Reactive Routing Algorithms

Compared to proactive routing algorithms witch keep concise routes, reactive routing algorithms calculates routing information only when data is ready to be transmitted adopting a lazy routing approach. The calculated path is considered valid as long as the destination is reachable or until the route is no longer needed.

So reactive routing protocols avoid the traffic flood and the overhead of periodic routing calculation, but that caused a delay between communication of two nodes can be established.

3.2.1 Signal Stability Adaptive Routing (SSR)

Signal Stability Adaptive Routing (SSR) is a reactive routing protocol, which calculates a route between two nodes based on the stronger connectivity which is calculated as the signal strength and stability of the nodes. SSR maintains two tables, a Signal Stability Table (SST), which stores the signal strength of neighbouring nodes, and a Routing Table (RT), which stores recent routes.

Generally, Routing in SSR is split in two internal protocols, the Dynamic Routing Protocol (DRP), which administers the SST and the Static Routing Protocol (SRP), which administers RT.

Initially, packets are received and processed by the DRP, based on the obtained information DRP updates SST and forward the packets to the SRP. SRP looks up the destination in the RT. In case of a valid entry it forwards the packets. Otherwise, it initiates a route-search to find a route.

If a node receives a route-request packet, it forwards the packet to the next hop only if the packet is received over a channel with stronger signal strength and has not been previously processed.

The destination node sends a route-reply message back to the initiator, in acceptance that the first packet arrived over the shortest path. Based on this route-reply message, routes along the path update their routing tables.

3.2.2 Temporally Ordered Routing Algorithm (TORA)

Temporally Ordered Routing Algorithm (TORA) is highly adaptive, distributed, scalable and reactive algorithm which is based on the concept of link reversal. It presupposes same time base on all nodes.

TORA has three basic functions: Route creation, Route maintenance and Route erasure. The route creation algorithm generates a directed acyclic graph from source to destination based on a propagation parameter, called "height". A node with higher height is considered upstream and one with lesser downstream. The algorithm starts by stetting the height of the destination to 0 (base) and all other node's height undefined (NULL). Now the source broadcasts a "route query packet" containing the destinations' ID. Each node with non-NULL height responds with an update packet, witch including its height in it. If a node receiving an update packet compares its height with the packet height. If it is more than 2, a short path to the source exists. Now it updates its own height to the packet height plus 1 and propagates the update packet with its own height in it. In Figure 3 you can see an example of the TORA route creation algorithm.

TORA is the most elegant and complicated approach for solving Routing Problems. It creates a couple of alternative ways to destination. In large, fast changing networks TORA is worse than other protocols. Nevertheless the overhead increases in case of reconfiguration after link failure.

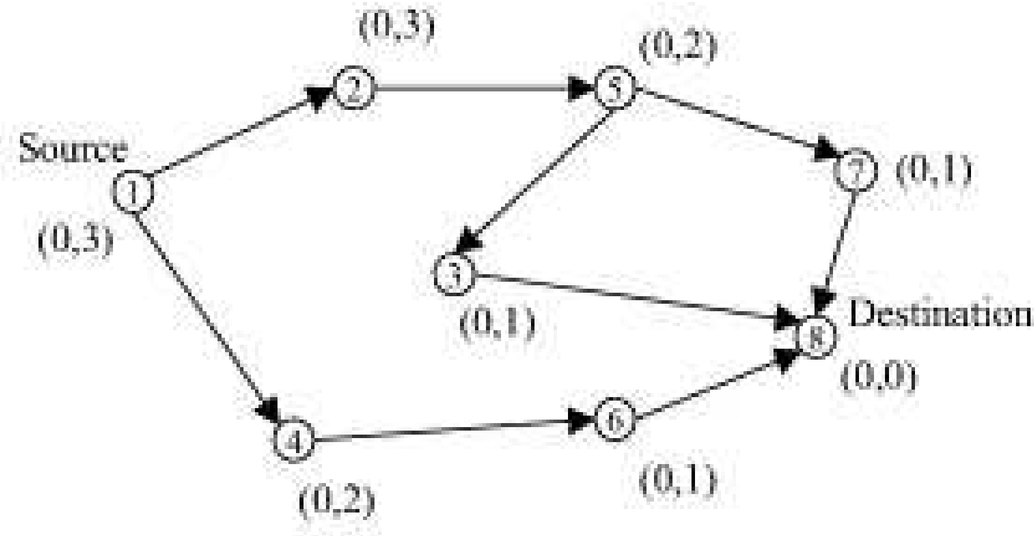


Figure 3: Example of TORA route creation algorithm

3.2.1 Ad Hoc On-Demand Distance Vector Routing (AODV)

Ad Hoc On-Demand Distance Vector Routing (AODV) is a simple reactive algorithm which improves table-driven DSDV.

Instead of maintaining a list of tables, AODV minimizes the number of broadcasts by creating routes on demand.

AODV is based only on symmetric bi-directional links. If a route is required, the source broadcasts route-request packets (RREQ) to neighbours which forwards it to all neighbours and so on, until it reaches the destination. You can see an AODV route creation example on Figure 4.

When a node forwards a route-request packet, it also records that the packet visited that node in order to be able to construct the reverse packet for the route-reply packet.

The destination node chooses the shortest path and sends a reply packet (RREP) and all intermediate nodes enter the route into their routing tables.

On link failure or source changes, the algorithm is re-initiated (RERR).

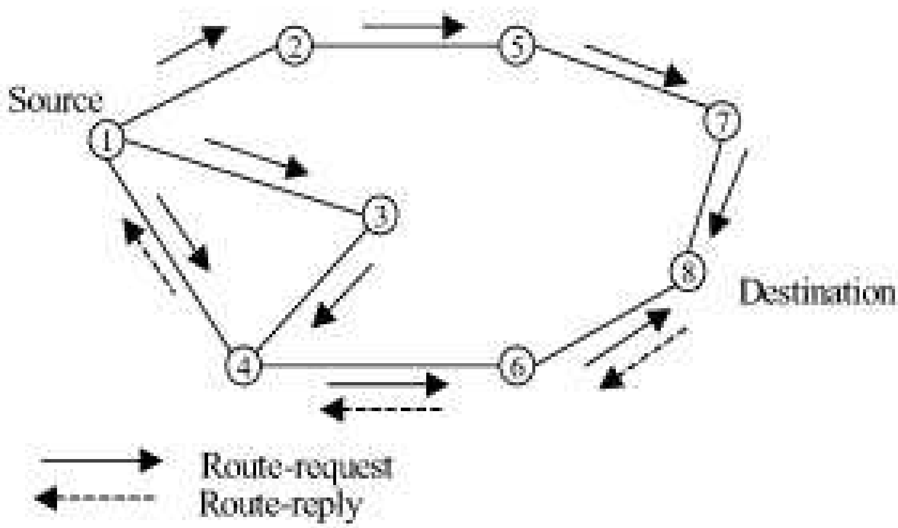


Figure 4: Example of AODV route creation

3.2.1 Efficient Route Update Protocol (ERUP)

Efficient Route Update Protocol (ERUP) is based on AODV and combines routing with power saving.

The Route update in ERUP is divided in two steps. Nodes along the old route broadcast locally a Route Discovery Region packet (RDR). This RDR defines the spreading area of Route Request packets (RRQ). Now the source node releases RRQ, and only nodes within the RDR can rebroadcast this RRQ.

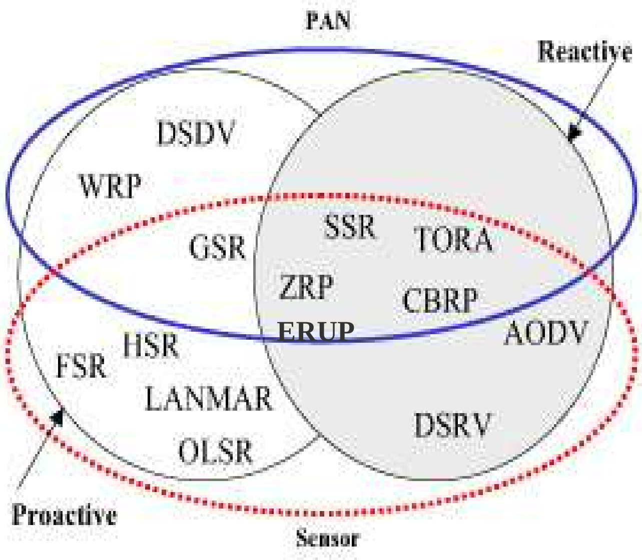
So update activities are confined to a narrow strip exactly covering the old route which makes the discovery overhead very small and a new route mostly overlaps the old route.

Each node sends a warning signal if its power falls down. The source initiates the route update process, if 70 % of the nodes along the path have sent warnings, or a "powerful" node enters an active route, or a node is out of order.

4. Conclusions

One of the most important issues in PAN and sensor networks is efficient routing which can be achieved if each node has already a clear image of the current network topology. Considering both efficient routing and power limitation, we need to find a compromise between up-to-dateness and extra overhead in order to get a clear view about the network topology.

This paper presents a review of the most important algorithms for PAN and sensor networks. They can be grouped into two categories, namely, the proactive approach and the reactive approach. Existing algorithms can be summarized in following figure.



The major advantage of the proactive routing algorithms group is that the communication between two nodes can be established within a minimal delay, and the route can be selected from the routing table. When proactive routing algorithms are used for PAN, the number of devices is rather limited and the network topology does not change rapidly, this advantage becomes more apparent.

In sensor networks, in comparison, the number of nodes is larger and the network topology can change more frequently. In this case, periodic proactive routing calculation for all nodes increases the system overhead but without a large advantage. In addition, to maintain a routing table for a large sensor network in a mobile node increases the system requirements. Only proactive algorithms which organize the nodes in groups, clusters and hierarchies fit well in sensor networks.

The most reactive routing algorithms are applicable for sensor networks, and some of them can also be used for PAN, but they have an obvious disadvantage compared with proactive routing algorithms.

In summary, none of these algorithms covers all applications; they all have their advantages and their disadvantages. The final selection of which routing algorithm fits best should be based on the specific network application.

References

[1] P. Trakadas, Th. Zahariadis, S. Voliotis, and Ch. Manasis, “Efficent Routing in PAN and Sensor Networks”, ACM SIGMOBILE Mobile Computing and Communications Review, Volume 8, Number 1, 2004.

[2] Xuhui Hu, Yong Liu, Myung J. Lee, Tarek N. Saadawi, “A Novel Route Update Design for Wireless Sensor Networks”, ACM SIGMOBILE Mobile Computing and Communications Review, Volume 8, Number 1, 2004.

[3] Abouda Abdulla, “Routing Protocols for Ad Hoc Mobile Wireless Networks”, lecture notes for Seminar Ad hoc Networks, Communication Laboratory, Helsinki University of Technology, 2003.

[4] Melitta Dragaschnig, Robert Kuschnig, “Routing in Ad-Hoc-Netzwerken”, University Klagenfurt, Seminar für Rechner- und Netzarchitektur, 2003.

[5] A. Tanenbaum, “Computer Networks“, Prentice Hall Inc, USA 1996.

[6] R. Ritabrata, “Indroduction to Ad-Hoc Network Routing Algorithms”, Final Term Paper, ECE 253, George Washington University, April 2002.

[7] C.E. Perkins, P. Bhagwat, “Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers”, Computer Communications Review, October 1994, pp. 234-244.

[8] C. E. Perkins, E. M. Royer, S. R. Das, “Ad Hoc On-Demand Distance Vector Routing”, October 1999, IETF Draft, draft-ietf-manet-aodv-04.txt.

[9] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, “A Survey on Sensor Networks”, IEEE Communications Magazine, August 2002, pp. 102-114.