On-demand Construction of Non-interfering Multiple Paths in Wireless Sensor Networks

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Abstract: In this paper we present a routing scheme for on-demand construction of multiple non-interfering paths in wireless sensor networks. One usage of this multipath scheme is to provide a source the ability to increase the likelihood that its data reaches the sink by sending a copy of a packet on more than one path. The routing scheme is based on the assumption that the sensor nodes are aware of their geographic position.

1 Introduction

Multipath routing aims at establishing multiple paths between a source and a destination. In wireless sensor networks, multipath routing is used to increase the reliability, i.e. the likelihood that (important) data eventually reaches the destination in the face of failing nodes [GGSE01, DNWH03]. While multipath routing is efficient, most of the schemes that send packets on each established paths suffer from a problem called route coupling problem [PHST00]. Route coupling means that packet transmissions on one path interfere with packet transmissions on another path.

Geographic routing is a routing scheme where the location of the network nodes is used to decide which path data packets should go through the network. In order to scale, geographical algorithms commonly use *greedy* strategies, where forwarding decisions are made locally based on information about their one-hop neighborhood [KK00]. A packet is forwarded to a neighbour closer to the sink/destination than the node itself until the packet reaches the sink. There exist several approaches to handle packets that get stuck in local minima, i.e. places where all one-hop neighbors are further away from the destination [FGG04, KK00].

In this paper, we present a simple routing algorithm for on-demand construction of multiple non-interfering paths in a wireless sensor network where nodes are aware of their position and hence geographic routing can be employed. The main idea is that a node chooses a node as next hop only if the node's distance from the straight line between the source and the sink of the data transfer is at least the transmission range. This way, it is straightforward to send copies of a packet along two non-interfering paths between source

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and sink without performing route discovery or any other routing overhead. In order to make appropriate forwarding decisions, nodes must know their transmission range. We present simulation results that show that this can be done using local knowledge, i.e. it is sufficient that nodes know their neighbours' locations.

2 On-demand Construction of Non-interfering Paths

2.1 Motivation

Most of the protocols for multipath communication in wireless networks have proposed to use either disjoint routes [GGSE01] or partially disjoined routes, also called meshed routes [DQW03]. While these approaches increase reliability or throughput, they still have the problem that the paths interfere, i.e. the packets on one path can interfere with the packets on another path. This problem is called the route coupling problem [PHST00]. Our aim is to route packets along paths with as little interference as possible.

For our discussion, we assume that we want to send copies of all packets on both paths, i.e. the second path is not only maintained as a secondary path, but actively used. A source might choose to send data on multiple paths to increase the likelihood that the data arrives at the sink when the data is considered important, for example, a sudden significant change of a measured value. We also assume that all nodes know their next-hop neighbours and their position. A further assumption is that the transmission ranges of nodes are isotropic.

2.2 Path Construction

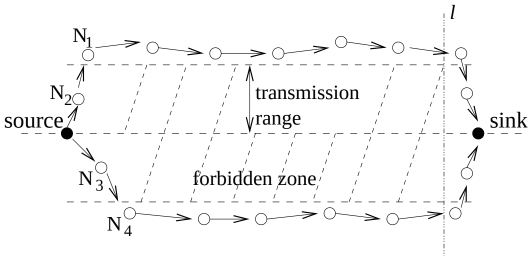

Figure 1: Multipath construction

Route construction Using geographic routing it is straightforward to construct two paths that do not interfere. As shown in Figure 1, if each node on a path has a distance of at least one transmission range from the line between the source and the sink, the minimum distance to a node on the other path is at least twice the transmission range. If we assume that the interference range is twice the transmission range, this implies that a packet transmission on one path does not interfere with a packet transmission on the other path. The only exception are the nodes in proximity to the source and the sink.

Using greedy geographical routing a node forwards a packet to another node closer to the destination than the node itself [KK00]. Local minima can be handled as in other geographic routing schemes [KK00, FGG04]. In order to provide non-interfering paths, we also demand that the distance between the next-hop from the line from the source to the sink is larger than the transmission range. Thus, we implicitly span a *forbidden zone* as shown in Figure 1[1]. In order to span the forbidden zone, nodes need to know the following information which can be provided in the packet header: location of source and sink, a bit denoting if the packet should travel above or below the line between source and sink as well as the maximum transmission range.

Nodes close to sink and source There are at least two possible approaches to avoid interference on the first hop, i.e. for the source when transmitting data. In the simpler the source sends the two packets time-shifted: the first one to the receiver in the "upper" part of the forbidden zone, the second one with some delay to the receiver in the other part of the forbidden zone. Note that such a scheme does not imply that we can be sure to avoid any interference. Due to link-level retransmissions the packet sent later might "catch" up with the packet sent earlier. In addition, the number of hops may differ leading to the same phenomena.

The second approach is to make the source multicast one packet to both first-hop receivers (node 2 and 3). In order to avoid that the packets the first-hop receivers forward interfere with each other, these nodes can compute a random delay, based on their location, for forwarding the packet. In certain cases, it is even possible that the two transmissions from node 1 to node 2 and from node 3 to node 4 can be performed in parallel without interference. If the source multicasts a packet to both node 2 and 3 including their geographical addresses, node 2 learns the location of 3 and node 3 learns the location of 2. In that case, node 3 can select a minimum transmission power required for its transmission to node 4 (which is assumed to be further away from node 2 than node 3). Assuming that node 2 also selects the minimum transmission power to reach node 1, node 3 can calculate whether its transmission to node 4 decreases the signal-to-noise (SNR) ratio at node 1 below a given threshold value. For example with a minimum SNR = 10 dB and an attenuation factor of 4, we need: $D/R > 1.78$ (D: distance between nodes 2 and 3, R: distance between node 3 and 4). Node 2 can perform calculations in a similar way.

For the nodes in proximity to the sink, we must define when a packet is allowed to enter the forbidden zone when it approaches the sink. A simple possibility is to define a line l (see Figure 1) as a boundary for the forbidden zone. Future work needs to evaluate different possibilities.

Limitations There is one limitation of this scheme. Assume both packets get stuck, but there is a path in the forbidden zone. One solution to the problem is that packets that get stuck report this to the sink (by travelling backwards on the same path which requires

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[1] We introduce this term for simplicity without defining the edges close to source and sink.

nodes to keep some soft state). If both packets get stuck, the source can decide to use another routing scheme, i.e. not multipath.

3 Experiments and Conclusions

We have implemented our multipath construction scheme in the Contiki network simulator. Contiki is a lightweight system for communication-oriented, memory-constrained devices such as sensor nodes [DGV04]. In the Contiki network simulator each sensor node is represented by its own Linux process. A network layer simulation connects the processes. This network layer detects when collisions occur using a simple model: When a sensor node, represented by a Linux process, sends a packet and another node within the configurable radio transmission range starts transmitting another packet while the transmission is ongoing, both packets are destroyed. Otherwise, the packet is delivered to the receiver.

Simulated scenario In our simulated network, a certain number of nodes are distributed randomly over 310x300 area. The transmission range is set to 35. Packets are sent from the source located at $(10, 150)$ to the sink at $(300, 150)$ using multipath routing as described above. In our experiments, we vary the number of nodes that are distributed over the area.

Results Using the Contiki simulator, we have verified that our approach indeed constructs non-interfering paths except for the nodes in close proximity to the source and the sink.

One property of our approach is that nodes need to know their transmission range since it is required to calculate the forbidden zone. As noted above, we have set the transmission range of nodes to 35. While one could assume that all nodes know their transmission range, this is of course a simple assumption and also prohibits the adaptation of individual nodes' transmit power levels. Therefore, we have made experiments, where the nodes estimate their transmission range based on the distance to their most distant one-hop neighbour.

The results of this estimation our shown in the left part of Figure 2. It shows that the estimation of the distance based on the most distant one-hop neighbour is actually quite exact both for dense networks as well as sparser networks, despite that the number of neighbours increases with the dense of the network as shown in the right part of Figure 2. The results show that it is feasible to add the maximum transmission range a node has estimated as a parameter in the packet header. This parameter can be updated by a node that has estimated a higher value than the current one. The node's own estimation works well for the following reasons: In very dense networks, there is always a very distant one-hop neighbour. In sparser networks, nodes have either one-hop neighbours within a distance that is close to the transmission range, or no path is found.

Our results also show that the number of hops on the two paths differ quite often. As expected, the difference is larger for sparse networks than for dense networks. In sparse

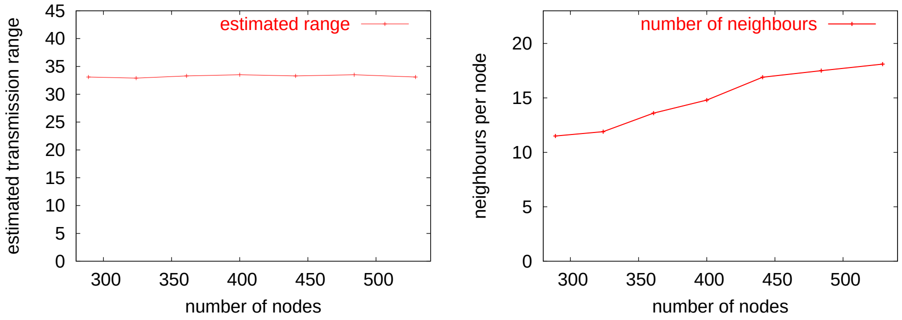

Figure 2: Estimated transmission range (left) and average number of neighbours per node (right)

networks, the chance that a hop that does not lead the packet closer to the destination has to be made is larger than in dense networks.

Conclusions In this paper, we have presented a routing scheme that establishes multiple non-interfering paths. The scheme enables a source to route data along two paths without any routing messages.

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