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Improved geographic routing in sensor networks subjected to localization errors

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ABSTRACT

Geographic routing strategies used in wireless communication networks require that each transmitting node is aware of its location, the locations of its neighbors, and the destination. With this information, the message is routed by choosing intermediate nodes, or relays, which allow the destination to be reached with the maximum possible transmitted information rate and with minimum delay. However, this strategy needs to take into account the uncertainties of the relays locations in order to avoid an important performance degradation of the link, or even a routing failure.

Taking into account the presence of uncertainties in the relays locations, each possible geographic routing strategy is able to recognize a subset of nodes that can be candidates for relays. Furthermore, the transmission range between nodes not only depends on the distance between them, but also the communication channel fading. Based on the effect that these uncertainties have on the link channel capacity, a minimization of a cost function is proposed to decide the next hop relay, which optimizes, in mean, the maximum rate of information transmitted with the minimum number of hops. Using the location statistics, this optimal strategy is applied for both one-hop decisions and two-hops decisions. Working expressions for on-line fast calculations are provided and used for results illustrations.

1. Introduction

The solid wireless sensor networks information processing approach is based on a canonical problem formulation of localizing and tracking moving objects [1]. Location-aware personal devices and location-based services have become ever more prominent in the past few years (see [2,3]). Moreover, geographic routing protocols show high performance and are considered as promising candidates for large-scale ad hoc networks. These protocols carry low overhead as they do not require a route management process. These routings use location information, so that each transmitting node is aware of its location, the locations of its neighbors – called relays – and the destination. The routing decision is made locally, where every node forwards the packet to the most promising neighbor towards the destination.

Geographic routing protocols use geographic forwarding by assuming ideal conditions [4]. However, under realistic situations such as location errors, obstacles, and radio irregularity the performance degrades or may lead to routing failures. In [5] the authors concludes that a reception-based forwarding strategies in realistic conditions are generally more effective than distance-based strategies but this could be at the cost of lower energy efficiency. The performance of geographic routing, based on the assumption that the location of each node is accurate, can be greatly improved when location uncertainties and channel transmission properties are taken into account.

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Taking into account the presence of uncertainties in the relays locations, and also the communication channel fading, in this work, a minimization of a cost function is proposed to decide the next hop relay. The factors to consider in defining appropriate metrics in the cost function are: (i) Low probability of data loss; (ii) maximum rate of information arrival to the destination; and (iii) minimum impact of signaling and control on effective data rate. In order to achieve an efficient relay selection that takes into account all these factors, in this paper the channel capacity, together with the uncertainties statistics, will be considered as a basis to derive formal expressions of two metrics. One is the probability of error, defined as the relative amount of information lost when nodes have uncertainty in position and are subject to fading noise. The other is the progress of information in terms of the expected distance between hops toward the destination. Since a greater progress information implies an increase in the probability of error, the optimal selection of the next relay toward the destination should be a trade off between the two metrics. In this paper, by using these two quantities, we define a cost, which weighs in a relative way both the probability of error and the progress of the information. Based on a subset of possible relays, the one which optimizes the proposed cost function is selected. In this way, we obtain optimal relay selections, in the sense of minimum probability of error and maximum information progress.

The remainder of this paper is organized as follows: In Section 2, a discussion of recent works that address strategies to improve geographic routing in networks subject to uncertainty, and the relationship with our approach, is performed. In Section 3, based on the location statistics and their influence on the channel capacity we define and derive the proposed metrics. In Section 4 we propose the criterion for the cost evaluation in order to decide optimally the relays. Also working equations useful to on line evaluate the metrics for one-hop and the two-hops cases are derived. The results for both selection cases using simulations for different uncertainties levels and different numbers of possible relay are shown in Section 5. Furthermore, these results are compared with other two different criteria, the greedy routing scheme (GRS), and the maximum expectation within transmission range (MER). Finally, we conclude the paper in Section 6.

2. Related work

The analysis in [6] shows that one of the main reasons of failures in face routing happen due inconsistency in the distance between two nodes caused by location errors. Their study shows that realistic location errors can in fact lead to incorrect (non-recoverable) behavior and noticeable degradation of performance on geographic routing. They find that in some cases, more than 10% storage failure of sensor network events can occur in the presence of 10% location error. These failures can be reduced by using improved protocols based on using extra local information exchange between nodes. They analyze and identify the error scenarios and propose modifications to eliminate the error and enhance the performance in both Greedy Perimeter Stateless Routing and in Geographic Hash Table protocols. In addition, to study the effect of location inaccuracy on greedy forwarding, an enhancement using mobility prediction models is proposed in [7]. Based on a stochastic decisions, in which each node performs on-line probing of its neighbors in order to decide the next hop, in [8] a strategy is proposed obtaining significant improvements with respect to the deterministic decision. In the cited references, the proposal to mitigate the problem of uncertainty in the location consists of reducing uncertainties either by adding predictive models, by improving measures, or by checking connectivity.

A different approach on how to mitigate the impact of location errors is discussed in [9]. Since it is assumed that each node knows its position and the position error variance, the authors propose to attach an error information field in a message for geographic routing and to announce the statistical characteristics of the location error to neighbors together with location information. With this information, they propose to choose the relay that maximizes the expected progress of information within the transmission range.

In this paper, we will also follow a stochastic approach, but we will consider different metrics and cost function, from those used in [9]. It is important to note the similarities and differences between both approaches. (i) As proposed in [9], we also consider that each node informs its neighbors about its own location error bound. Also, we use the progress in the cost function, but unlike [9], which uses the expected progress within the transmission range, our progress is the conditional expected value, given that the message was successfully received by the relay. This is a major difference, because the progress is calculated only considering the messages that are successfully received by the relay. (ii) Differently from [9], our cost includes a second metric, which is the probability that the message was actually received by the relay. This strategy allows us to get the optimal selection of relays that combine the maximum possible progress with the maximum number of messages successfully received. (iii) Additionally, our approach includes the uncertainty in the transmission range due to the fading of the communication channel. Formally speaking, the transmission range of a node, defined as the maximum distance within which a relay can receive messages, is given by the channel capacity of the link [11]. The channel capacity of the link depends on the signal-to-noise power ratio at the receiving node. The signal-to-noise ratio depends on the distance between the transmitter and the receiver, the thermal noise, the transmission power, the signal propagation constants, and also largely on the channel fading. In real conditions, the received signal strength at the relay is affected by multi-path or shadowing fading, which is usually modeled by a stochastic process with log-normal distribution. As a consequence, the transmission range must be considered as a stochastic variable for performance evaluation purposes. To this end, it is important to consider the channel capacity for each relay in order to evaluate the quality for routing information. In the presence of location uncertainties and fading, the channel capacity is a random variable from which both the probability that information reaches