Computer Networks 143 (2018) 191–205

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

EasyGo: Low-cost and robust geographic opportunistic sensing routing in a strip topology wireless sensor network

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ARTICLE INFO

Article history:
Received 21 June 2017
Revised 15 May 2018
Accepted 2 July 2018

Keywords:
Wireless sensor networks
Routing algorithms
Strip network monitoring

ABSTRACT

With the fast increasing popularity of smart device communication technologies, the wireless networks on mobile sensing applications have received much attention. Wireless Sensor Networks (WSNs) with a strip structure are ubiquitous in real world deployments, such as pipeline monitoring, water quality monitoring as well as Great Wall monitoring. However, the existing routing methods will select the next-hop node that deviates from the transmission direction to sink node in strip networks with high curvature, leading to the high communication failure rate and energy consumption. To this end, we propose a new geographic routing sensing opportunistic approach, named EasyGo, to cope with the routing problem, i.e., the transmission success rate decreases in the complicated strip networks. Specifically, by investigating the transmission direction, we propose a new candidate selection algorithm SLS, which introduces the concepts of layer slicing and virtual sinks to improve the transmission success rate in strip WSNs. Theoretical analysis and extensive simulations illustrate the high efficiency and transmission performance of the proposed EasyGo strategy for strip WSNs. Furthermore, we implement the EasyGo on the testbed with Z-Stack™ nodes. Compared with the classic algorithms, our EasyGo improves the transmission success rate by up to 10%, reduces the communication overhead and the energy consumption rate by up to 11.8% and 5%, respectively.

1. Introduction

With the fast increasing popularity of smart devices, the ubiquitous mobile sensing applications have received much attention, such as wireless sensor networks (WSNs). WSNs have been used for many long-term monitoring applications, such as underground railway monitoring, water quality monitoring [26,30], vehicle monitoring [18,27] and Great Wall monitoring. An effective routing strategy is critical for monitoring these applications since it can provide sufficient and real-time data.

Many recent studies have shown that traditional routing (TR) is highly unreliable on WSNs [31,35,43]. Specifically, TR is designed for wired networks where a single candidate node is predefined for packet forwarding. However, this single forwarder may be highly unreliable in a wireless environment, because the link quality of the predetermined forwarder may fluctuate and cause excessive retransmissions due to packet loss.

Recently, opportunistic routing (OR) [2,7,23] was proposed to cope with the unreliability of the single candidate in such wireless networks. The basic idea of OR is to select a set of forwarding candidates and chose one of them as the actual forwarding candidate according to its availability and reachability for each transmission. Thus, with the help of OR, the packet loss rate can be decreased in the wireless network.

Current OR methods, however, are facing the problem of high communication overhead in a large-scale deployment since they send hello packets and find the forwarding path along the whole network. In addition, communication overhead can cause resource depletion and increase the latency accordingly, which finally affects the real-time monitoring of applications.

The geographic opportunistic routing (GOR) [7,28,37,46], which is proposed as a supplement of OR schemes, has received much attention. GOR does not need to send hello packets and find the forwarding path along the whole network; instead, it makes the prob-

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https://doi.org/10.1016/j.comnet.2018.07.002
1389-1286/

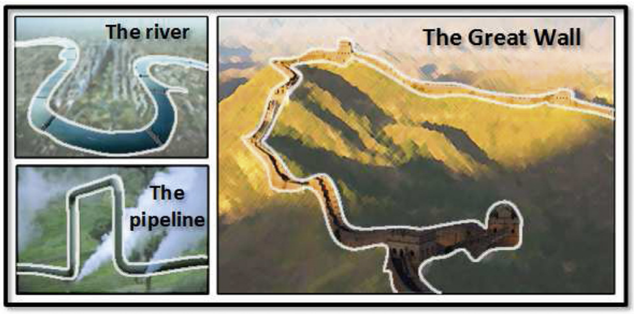

Fig. 1. The strip networks of river, pipeline and the Great Wall in real world.

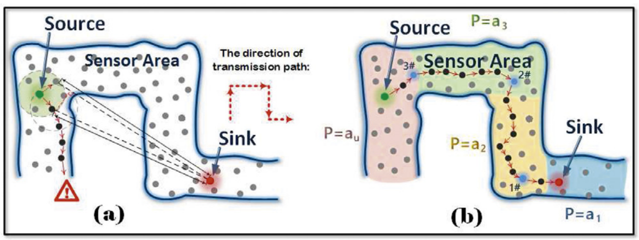

Fig. 2. The success and failure in strip network using GOR. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

abilistic forwarding decisions at the sender and each forwarder based on the node locations. Thus, the communication overhead can be minimized as compared with OR. Besides, GOR can be employed in many applications since the location of each node is known due to the pre-deployment or localization algorithms. In addition, the advantage of GOR is that nodes only need to know the local information of their one-hop neighbors, and can keep the minimum stored states and communication overhead. GOR receives a lot of research interests due to its low cost and less communication overhead, especially for those applications using pre-deployed nodes with known locations.

However, GOR method assumes that the network is in an ideal area without any turning point and the locations of each node is known, which is a strong assumption in most practical WSNs. In reality, strip structure networks are widely applied, such as pipeline monitoring, water quality monitoring, vehicle monitoring and Great Wall monitoring (shown in Fig. 1). In the strip structures, turning points will increase the difficulty in forwarding the packets. Specifically, a right direction always determines whether the transmission along the network succeeds or not. However, according to GOR, we cannot ensure the right direction towards the sink only by judging the distance between the sink and the node as shown in Fig. 2(a). Thus, the GOR strategy will fail to transmit the packets to the sink at each turning point. Consider a simple application of indoor moving target tracking system [34], where the areas are not ideal in regular geometric shape. Based on the structure of the building, most of them are strip structures with several turning points. By using traditional GOR on the above areas, the packet transmission will fail at the turning points since the selected candidate is not in the right direction towards the sink. Similar cases of this type of strip networks can be widely found in our daily life, such as real-time monitoring of underground railway, the pipeline monitoring for transporting oil, and animal conservation monitoring in the wild mountain ridge environment.

In order to better understand why traditional GOR will fail to transmit the packet at the turning points, we tried to apply the GOR to various well-known applications. For example, the Great Wall, known as one of the eight wonders of the world, was set as a strip network for experiment. We observed that traditional GOR methods, such as the GeRaF [46], assign the candidate sets that are close to the sink with high relay priorities. It cannot choose the next-hop candidate sets among the strip network with turning points in the right direction, and thus the data transmission failed.

To overcome the drawback of the traditional GOR methods, in this paper we propose a new low-cost and robust GOR strategy in strip networks, which brings both the layer slicing and virtual sinks to GOR in strip WSNs (we simply call this strategy as EasyGo) and contains two different levels of regional division to ensure a precise transmission direction towards the sink.

Compared to the traditional GOR, we solve the transmission problem based on the geographic and opportunistic routing strategy, but the difference is that we divide the winding paths of the strip network into several relatively straight regions for successful candidate selection.

To do so, we divided the routing strategy into two parts: candidate sets selection and forwarding strategy. For the first part, we provide a coarse-grained layer slicing, called the turning-points-divide technique (TPD), to turn the strip network into several straight sub-regions. After that we select a virtual sink at each turning point to collect the data of its sub-layer and transform it to the next sub-layer, By doing so, the candidates could be selected in the right direction. The second part is the forwarding strategy where we carefully select a single forwarder among the candidate set. Combining this two parts, the success rate of routing can be improved.

We introduce a Strip Layer Slicing algorithm (SLS) to handle the problem of candidate set selection in the right direction. SLS can solve most of the cases when the current nodes are in the middle part of the sub-layer, however, it does not work well in some special cases where the nodes lying on the boundary of the layer, and it even increases the packet loss rate. Thus, the challenge is how to improve the success rate of the candidate set selection. In order to solve this problem, we then improve SLS algorithm, to achieve a higher success rate of candidate set selection in the above cases. In addition, we analyze the thresholds of the deployment density ρ and distance d from the source node to the sink in order to limit layer slicing, and ensure the success rate of transmission and power saving as well, which are also verified by the simulation results.

Unlike the existing approaches that can be only used in the regular shape network structures, in this paper we focus on the real deployments which have the strip network structure in nature.

To illustrate the proposed EasyGo approach, we show a simple example of strip network with three turning points in Fig. 2. We define the correct transmission direction with the red dotted line, in which the selection of the candidate sets and the future forwarding path can always reach the sink. Obviously, judging by the geographic information of the nodes and the sink, the forwarding path may be misled in a wrong direction. Thus, the routing strategy with high success rate and low energy consumption needs to take the global information of a strip network into consideration, and transmits data in the right direction.

So how can we ensure the transmitted data in the right direction? To do so, we divide the whole strip network into several sublayers denoted as a_1 to a_u, and choose a virtual sink i# at each turning point to collect the information of the sub-layer. As shown in Fig. 2(b), the current virtual sink will pass the data package to the previous virtual sink $(i-1)$#, till the data is transmitted to the real sink. This process ensures the right direction of data transmission.

From the above example, it can be seen that the key challenge is how to design a useful method for the candidate set selection, which takes both the geographic information and the transmission direction into account to ensure the routing efficiency. That is, the