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A 3 - D geographic location routing protocol based on forward region adaptive

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Abstract. In the application environment of real wireless sensor networks (WSNs), sensor node is located in a 3-D space. Therefore the conical forwarding region-based geographical (CFRG) routing protocol is proposed. In order to reduce the number of redundant data packets and reduce the collision probability of data packages, GFRG will establish a conical forwarding region to limit the number of forwarding nodes. In the case of void node problem (VNP), the node will adaptively adjust the volume of conical forwarding region and expand the space of forwarding node selection, namely solve the VNP by adjusting conical forwarding region. The simulation result shows that such CFRG proposed is able to solve the VNP. Comparing with similar 3-D routing protocol, CFRG can improve the performances of end-to-end transmission delay and data packet loss rate.

Key words. Wireless sensor networks (WSNs), Geographical Routing Protocols (GRPs), 3D, Conical forwarding region, Void node problem (VNP).

1. Introduction

With the rapid development of sensing technology, the wireless sensor networks (WSNs) have been widely applied. It collects environmental data firstly and transmits the same to the base station by deploying WSNs sensing node, then finally transmits the data to back-stage managers through Internet to realize the propose of real-time monitoring environment. A real-time and reliable data packet [4] transmission is required by those. Comparing with topology routing, the Geographical Routing Protocols (GRPs) dispense with routing maintenance and routing discovery phases, thus GRPs are able to provide reliable and real-time data packet transmission service [5, 6].

In the real WSNs environment, the sensing node is deployed in a 3D space, such

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as marine monitoring [7, 8] and forest fire sensing [9]. Aiming at these applications, the 3D position coordinates are required to be used by GRPs. However 2D GRPs is inconsistent with real 3D space because the route is selected by using flat routing technology only. The experimental results of literature [10–12] show that 3D GRPs can improve the reliability of data packet transmission.

Moreover, the key to GRPs is providing node with location information, and the 3D information [13] of node can be obtained by using GPS system. Another problem on GRPs is void node problem (VNP). VNP means there is no forwarding node in the direction of node sending. 2D GRPs usually solves VNP by flat routing technology. However these technologies cannot be applied in 3D GRPs.

For this reason, the conical forwarding region-based geographical (CFRG) is proposed in the paper. CFRG control the redundancy of data packet and compute the forwarding probability by establishing conical forwarding region to choose data packet for node transmission with maximum probability. Meanwhile CFRG adjust the conical forwarding region in real time to make it contain more nodes to improve the selection space of forwarding node selection. The experimental result shows that the CFRG proposed is not only able to reduce the transmission delay and loss rate of data packet, but also can solve VNP effectively.

2. Constraint condition and CFRG introduction

2.1. Constraint condition

Assumed that there are N isomorphic nodes in wireless sensor networks, and randomly distributed in the region of interest; these nodes are static, and the transmission distance of every node is r meters; the 3D volume formed by N isomorphic nodes is V.

Moreover, assumed that all nodes in networks know the locations of destination nodes and source nodes; all the information have been loaded in the first part of data packet; in most WSN, all the destination nodes (base station) are deployed on desired location, thus the locations of destination nodes can be deemed to be known.

2.2. CFRG introduction

CFRG is designed to improve the data transmission efficiency and reduce the transmission delay. GFRG establishes a conical forwarding region firstly, and control the number of nodes in forwarding data packet to reduce the congestion. Meanwhile it preferentially selects the node with maximum probability as forwarding node to reduce the transmission delay of data packet.

Moreover another characteristic of CFRG is to solve the problem of 3D VNP, which also is a common problem of GRPs. CFRG solves VNP by adjusting the conical forwarding region in real time.

3. CFRG routing

3.1. Conical forwarding region PFR

Firstly define the forwarding region of data packet, namely the conical forwarding region. The nodes in such region are identified as potential forwarding node. In order to reduce the times of transmission, the conical forwarding region shall be small as far as possible. In another word, the conical forwarding region is expected to contain one optimal forwarding node. From another perspective, the conical forwarding region shall be big enough, namely the probability of optimal forwarding node contained in such region shall be improved as far as possible.

In the case of data packet to be sent by Source Node S, a conical forwarding region is established firstly. In order to reduce the times of transmission, the conical forwarding region is reduced as far as possible at the beginning to make it contain less but appropriate forwarding nodes. Thus there is an inverse proportion between conical forwarding angle β and network density $\rho = \frac{N}{V}$. The greater the network density is, the smaller the conical forwarding region is, or otherwise, the bigger the same is. Hereby original conical forwarding angle β_{init}:

$$\beta_{init} = \frac{360^0}{\eta_s} \tag{1}$$

Where $\eta_s = \rho \times V_s$, where V_s represents the circular region with a center of Source Node S and the radius of r.

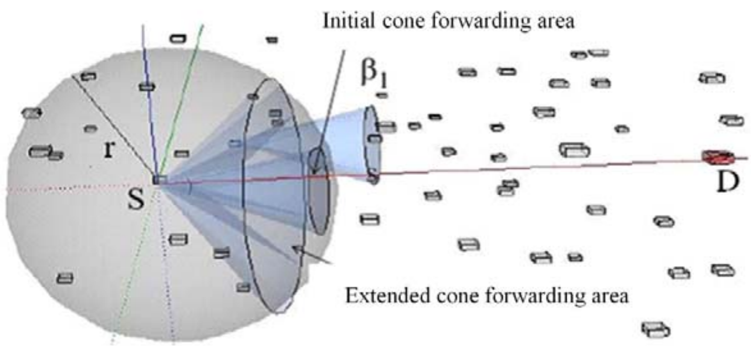

Fig. 1. Example of conical forwarding region

Establish an example of original conical forwarding region as shown in Fig. 1. It can be known from Fig. 1 that the volume of conical forwarding region is increased with the increase of value-β. β is controlled as a smaller value at the beginning. In the case of no appropriate forwarding node, the value-β will be adjusted gradually to increase the PFR region as shown in Fig. 2. Initially, a conical forwarding region is established on the base of β_{init}, and the region volume will be increased gradually if there is no forwarding node in it.

3.2. Forwarding node set

When receiving the data packet sent from source node or sending node S, the receiving node shall judge whether itself is in the conical forwarding region. If it is, then it will be a alternative forwarding node, namely it will be incorporated in the forwarding node set ψ.

Assumed that the position coordinates of node S is (S_x, S_y, S_z), and its position coordinates information is contained in the first part of data packet sent by node S; if any node (assumed as node n_i) receives such data packet, the node n_i will determine whether itself is in the conical forwarding region.

Assumed that the position coordinates of node n_i and destination node D respectively are (n_x, n_y, n_z) and (D_x, D_y, D_z). Firstly compute the included angle of two vectors: included angle θ of $\vec{SD}$ and $\vec{Sn}$:

$$\theta = \cos^{-1}\left(\frac{\overrightarrow{SD} \cdot \overrightarrow{Sn}}{\left\|\overrightarrow{SD}\right\| \left\|\overrightarrow{Sn}\right\|}\right). \tag{2}$$

Where $\|\overrightarrow{SD}\|$ and $\|\overrightarrow{Sn}\|$ respectively are vector modules, and $\overrightarrow{SD} \cdot \overrightarrow{Sn}$ represents the dot product of $\vec{SD}$ and $\vec{Sn}$.

Once the data packet is received, the node will compute the included angle θ immediately, and then judge the conformance of Formula (3), where β is the conical forwarding angle.

$$\theta \leq \frac{\beta}{2}. \tag{3}$$

In the case of conformity, such node is in the conical forwarding of forwarding region and is incorporated in alternative forwarding set $\psi(\psi \leftarrow n_i)$ as a potential forwarding node, or otherwise such data packet will be incorporated in $Void\_node\_packetlist$ for later processing.

Of course, all the nodes will be judged whether they are in the conical forwarding region in accordance Formula (3) at the beginning. In the case of data packet sent by sending node, if the node monitored still has not been forwarded after a period of time, it means such data packet has not been received by node. Thus the source node or sending node will resend such data packet and adjust the forwarding angle β. See Section 2.4 for detailed process.

3.3. Forwarding probability

(1) Time delay

In the case of more than one node in conical forwarding region, the forwarding probability of every node shall be computed. The forwarding probability mainly is computed by time delay estimation.

Firstly compute the time required by every node for transmitting data packet to destination node, namely the estimated transmission delay $\tau_{req}.\tau_{req}$ mainly depends on two factors: 1) hop count $h$between forwarding node n_i and destination node D;

and 2) delay per hop τ_h.

the hop count h can be determined by $\|\overrightarrow{SD}\|/r$, but the delay per hop τ_h depends on many factors, the definition is shown as Formula (4):

$$\tau_h = \tau_p + \tau_{pr} + \tau_q + \tau_t\,. \tag{4}$$

Where τ_p is the transmission time of data packet in medium; τ_{pr} is the time used by forwarding node to process data packet; τ_t and τ_q respectively represent the time and queue delay required by forwarding node to transmit data packet. τ_q can be ignored since it is the radio-frequency signal.

Thus, the total transmission delay τ_{req}:

$$\tau_{req} = (\tau_p + \tau_{pr} + \tau_t) + \left(h \times \frac{\|\overline{SD}\|}{r}\right)\,. \tag{5}$$

If delay τ_{req} is less than the data packet validity $T_{threshold}$ predetermined in the first part of data packet, such node shall continue to stay in PFR region, or otherwise shall be removed from alternative forwarding set ψ.

In the case of more than one forwarding node in alternative forwarding set ψ ($|\psi| \geq 1$), a node transmission data packet shall be further selected from it. Namely compute the "appropriateness" of forwarding data packet of every alternative forwarding node, and a node transmission data packet with highest "appropriateness" shall be selected. In the case of one forwarding node in alternative forwarding set $\psi(|\psi| = 1)$, the "appropriateness" is not required to be computed. In the case of no forwarding node in alternative forwarding set ($\psi = \phi$), it means no appropriate node forwarding data packet in PFR region, namely suffers VNP. See Section 2.4 for the process of VNP processing.

(2) Appropriateness

If the node is located in conical forwarding region, and finds it is able to transmit data packet before data packet validity $T_{threshold}$, then such node can be a potential forwarding node. If there is more than one node in conical forwarding region, it shall be further analyzed that which one is more appropriate to transmit data packet, namely the "appropriateness" of node to transmit data packet.

The node "appropriateness" can be estimated by using the queue delay of potential forwarding node and the average transmission delay τ_{av} of $m$data packets transmitted by it previously. Compute the delay τ_{av} by source node as shown in Formula (6).

$$\tau_{av} = \frac{\sum_{i=1}^{m} \tau_s^i}{m}\,. \tag{6}$$

Where τ_s^i represents the hop delay of i^{th} data packet measured by source node.

Finally, the forwarding probability of forwarding node p can be computed by

Formula (7):

$$p = \begin{cases} 1 - \dfrac{(\tau_{pr} + \tau_q + \tau_t)}{\tau_{av}}, & if \tau_{pr} + \tau_q + \tau_t < \tau_{av} \\ 0, & otherwise \end{cases} \tag{7}$$

Thus the value-p of every potential forwarding node can be computed according to Formula (7). The bigger the queue delay is, the lower the forwarding probability is. If no node transmits such data packet after the period τ_ω after sending node sends data packet, such data packet shall be transmitted again, and the original value-β_{init} shall be changed. See Section 2.4 for detailed process.

Finally, the node with maximum value-p shall be selected as the final data packet forwarding node $\hat{n}_f$:

$$\hat{n}_f = \max_{n_i \in PFR} p_i, n_i \in \psi\,. \tag{8}$$

3.4. VNP solving

Node may suffer routing void problem in GPRs, and it also is the common problem of GPRs. CFRG solves VNP mainly by adaptively adjust the volume of forwarding region, namely adjust angle β.

The adjustment mechanism of conical forwarding region is shown as Fig. 2. If there is no forwarding node in the forwarding region PFR_1 established on the base of original angle β_{init}, it may suffer VNP. Thus once the forwarding node S suffers VNP, the conical forward region shall be re-established. In the case of data packet sent by forwarding node S, if no data packet is re-transmitted by adjacent node after a period of τ_ω, it (forwarding node S) may suffer VNP. In such condition, the forwarding node S shall re-transmit the data packet. Moreover, time τ_ω can be adjusted according to Literature [14].

The nodes outside the original conical forwarding region shall confirm the ID number of data packet in $Void\_node\_packetlist$. In the case of data packet in its $Void\_node\_packetlist$, β will be doubled, namely increase the conical forwarding region to make it contain more potential forwarding node. Such process is called adjustment process of conical forward region.

The adjustment mechanism of conical forwarding region is shown in Fig. 2. Firstly source node S forwards the data packet by region PFR_1, and then finds there is no forwarding node in region PFR_1. So far adjust β to form region PFR_2. Finally, node n_1 is found in region PFR_3, and it is able to transmit the data packet to destination node. Although it is not the shortest path used by node n_1 to transmit the data packet to destination node D, but VNP can be solved.

In conclusion, the block diagram of entire CFRG is shown in Fig. 3.

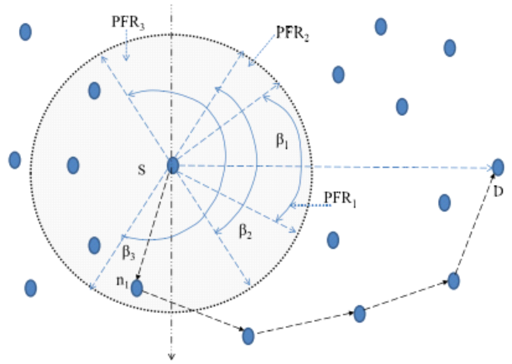

Fig. 2. Example of process of adjusting PFR region in 2d plane

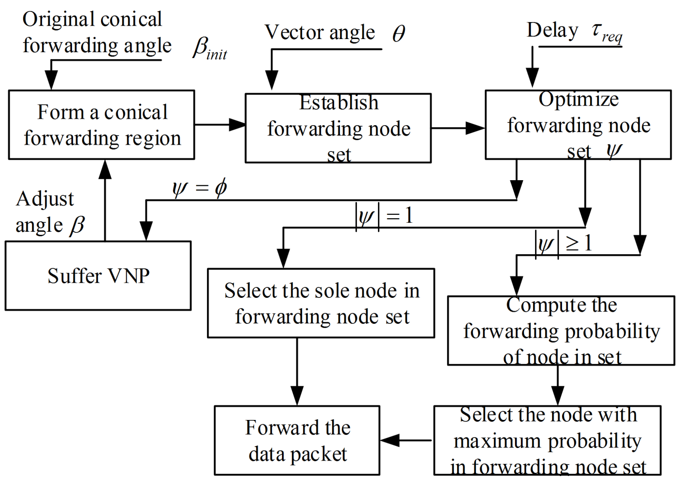

Fig. 3. Schematic diagram of CFRG to forward data packet

4. Numerical analysis

4.1. Simulation scene

A simulation platform is established by using simulation software - OMNeT++[15]. The time of simulation operation is 5 minutes, and the stopping time of every data packet is 250 milliseconds. See the simulation parameters as shown in Table 1 for details. Moreover in order to assess the performances of CFRG better, ABLAR and 3D Greedy routings are taken as references. The former solves 3D VNP by using random forwarding technology, and the latter belongs to typical GPRs strategy, which solves 3D VNP by using flat routing technology. Both are comparable with CFRG.

Table 1. Simulation parameter

Parameter	Value
MAC	IEEE 802.15.4
Propagation model	Logarithm-normal fading model
Fading variance (dB)	2.5
Size of data packet	32 bytes
Network area	500m*500m*200m
Number of nodes	change from 100 to 1000
Broadband	200Kb/s
Transmission distance	100m

During the analysis on CFRG performances, the end-to-end transmission delay and data packet loss rate shall be taken as performance indexes. Every experiment shall be made 10 times, and the average value shall be the final simulation data. The final simulation data is as shown in Fig. 5, 6, 7, and 8.

Analyze the end-to-end transmission delay and data packet loss rate of CFRG firstly, and make an analysis comparing with ABLAR and 3D Greedy routings.

4.2. Performance of CFRC

While analyzing the performance of CFRG separately, the end-to-end transmission delay, changes of data packet loss rate varying with conical forwarding angle β, and the changes of β from 0° to 360° shall be mainly analyzed. The simulation result is as shown in Fig. 4 and 5.

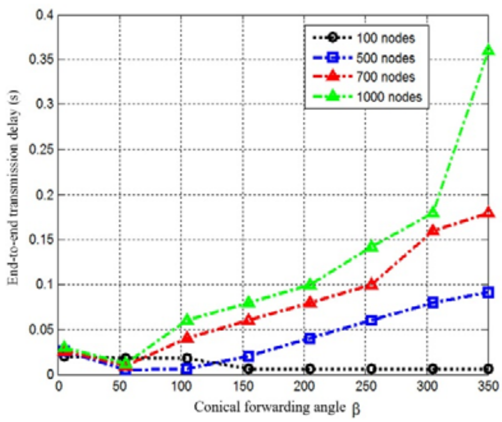

Fig. 4. Changes of end-to-end transmission delay varying with conical forwarding angle β

Fig. 4 is the changing curve of end-to-end transmission delay varying with β. It can be known from Fig. 4 that in network-dense region the bigger the β is, the larger the end-to-end transmission delay is, because: in dense region, once the β is increased, more nodes will need to forward data packet; thus the network congestion

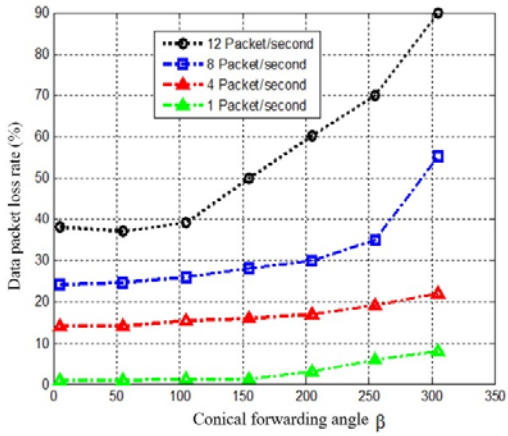

Fig. 5. Changes of data packet loss rate varying with conical forwarding angle β

will be aggravated, and the end-to-end transmission delay will be finally improved.

Fig. 5 is the changing curve of data packet loss rate varying with conical forwarding angle β. It can be known from Fig. 5 that in the case of large network loads ((12 packets/second), the conical forwarding angle β has an important influence on data packet loss rate. This is because: the greater the network loads are, the more the data packets to be sent by node are, which also will cause a congestion of data packet transmission, even cause data packet collision, thus the data packet loss rate will be increased. It is shown from the data that choosing appropriate β in accordance with network density is vary important.

4.3. Conparative analysis

In the section, it is mainly to analyze the influence of network flow on end-to-end transmission delay and data packet loss rate, in which the network flow is represented by the number of data packets generated by source node per second. Assumed that there are 1000 nodes and 4 source nodes in network, and the data packets generated by source node per second is changing from 1 to 14.

(1) End-to-end transmission delay

Firstly, the changes of end-to-end transmission delay varying with network flow are analyzed as shown in Fig. 6.

It can be known from Fig. 6 that the end-to-end transimission delay of CFRG proposed is the lowest relative ro 3D Greedy and ABLAR, and its fluctuation varying with netwrok flow is small. It is mainly because that when CFRG is making a decision on forwarding data packets, the forwarding congestion problem is taken into consideration, the forwarding rate is integrated into delay information, and it is conductive to reduce the congestion rate .

(2) Data packet loss rate

Data packet loss rate is an improtant indicator to reflect the perforamce of routing protocol. The changing curves of data packet loss rates of three protocols varing

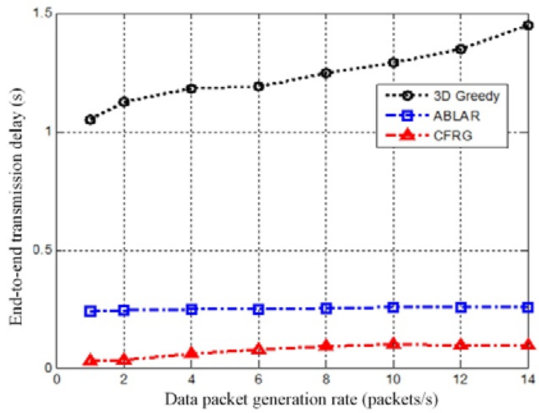

Fig. 6. Changes of end-to-end transmission delay varying with network flow

with netwrok flow is as shown in Fig. 7. It can be known from Fig. 7 that the data packet loss rates of three protocols are increased with the increase of network flow. Comparing with ABLAR and 3D Greedy, the data packet loss rate of CFRG is lowest, especially under the condition of low netwrok flow, so the advantage of CFRG in data packet loss rate is obvious. For example, in the case of low network flow, namely in the case of data packet generation rate not more than 6 packets/second, the average data packet loss rate of CFRG is about 8%, but 3D Greedy and ABLAR respectivly up to 32% and 44%.

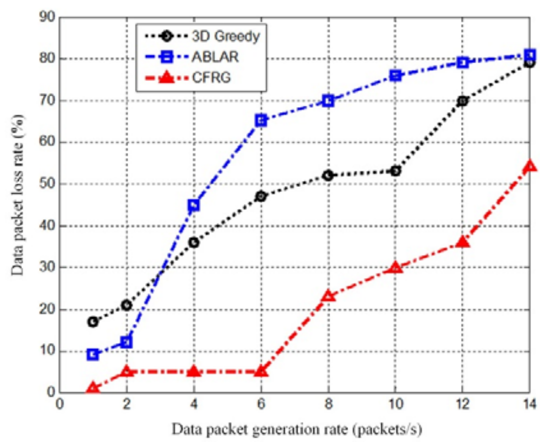

Fig. 7. Data packet loss rate

However, when the data packet generation rate is more than 6 packets/second, the data packet loss rate of CFRG will be increased sharply. Even so the data packet loss rate of CFRG still far superior to ABLAR and 3D Greedy, because CFRG is bale to adjust and expand forwarding region in real time, and has increased the space of forwarding node selection, then it is beneficial to solve VNP.

5. Conclusion

Aiming at the routing problem of wireless sensor networks, a conical forwarding region-based geographical (CFRG) is proposed in the paper. CFRG establishes conical forwarding region through network density with full consideration of the 3D spatial characteristics of node location. Only the node in conical forwarding region is able to forward data packet, thus the number of data packet to be forwarded can be controlled and the collision probability of data packet can be reduced in this way. Once the node suffers VNP, the conical forwarding region will be adjusted. Finally preferentially select the forwarding node to transmit data packet by computing the forwarding probability of every node in conical forwarding region. The simulation result shows that the CFRG proposed is able to solve VNP effectively. Comparing with similar 3D geographical location routing, CFRG has reduced the transmission delay of data packet and improved the success rate of data packet transmission.

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