Organized Topology Based Routing Protocol in Incompletely Predictable Ad-hoc Networks

Jian Shen^{a,b,c}, Chen Wang^c, Anxi Wang^c, Xingming Sun^{a,c}, Sangman Moh^d,
Patrick C. K. Hung^{c,e,*}

^a*Jiangsu Engineering Center of Network Monitoring*

^b*Jiangsu Collaborative Innovation Center on Atmospheric Environment and Equipment Technology*

^c*School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing, China, 210044.*

^d*Department of Computer Engineering, Chosun University, Gwangju, Republic of Korea*

^e*Business and Information Technology University of Ontario Institute of Technology (UOIT), Canada.*

Abstract

Nowadays, ad-hoc networks are becoming increasingly popular and has been put into practice in many kinds of applications. However, in some environments, such as ground temperature monitoring or medical and health care, the traditional routing protocols are not proper, due to the fact that the topologies of these networks are relatively stable in a very long period. Such networks are defined as the incompletely predictable network. Nodes in such networks move only in a limited range from the basic positions which are initiated at the very beginning. In this paper, we propose a new protocol named Organized Topology Based Routing (OTBR) to adapt to the environments mentioned above. It is worth noting that the concept of Organized Topology (OT) can be divided into two different situations: one is called the Static Organized Topology (S-OT) and the other is called the Dynamic Organized Topology (D-OT). Moreover, a new concept named “anti-pheromone” is put forward to achieve high energy efficiency. In particular, a Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is presented on the basis of the characteristic of S-OT.

*Corresponding author

Email addresses: s_shenjian@126.com (Jian Shen), wangchennuist@126.com (Chen Wang), Anxi_wang@126.com (Anxi Wang), sunnudu@163.com (Xingming Sun), smmoh@chosun.ac.kr (Sangman Moh), patrick.hung@uoit.ca (Patrick C. K. Hung)

Preprint submitted to Journal of L^AT_EX Templates

June 12, 2016

In addition, according to the feature of D-OT, Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) is proposed. Simulation results show that APS-OTBR has proper utilization ratio of nodes to achieve energy efficient, and GrD-OTBR has a stable performance when network size changes. Last but not least, to achieve higher node utilization, a new concept of equilateral triangle topology is proposed.

Keywords: Organized Topology, anti-pheromone, routing protocol, ad-hoc network.

1. Introduction

A wireless ad-hoc network (WANET)[1, 2] is a self-configuring, decentralized type of wireless network. With every node that participates in routing, the main characteristic of ad-hoc network is the complete lack of pre-existing
 5 infrastructure such as routers in wired networks. There are a lot of papers talking about time-evolving and predictable networks[3, 4, 5], where the positions of nodes and link status are predictable in a long period of time. However, the predictable network has certain limitation due to the preset network structure.

In this paper, we construct several models for one kind of ad-hoc net-
 10 works which has no need for nodes to move or whose nodes move in a very limited area around the basic position that has been initially settled at. We call such networks the incompletely predictable ad-hoc networks. In this kind of network, the movement of the nodes and information interaction is not such complicated as that in the classic ad-hoc models. What's more, repair-
 15 ing link failure is not so difficult as well. It becomes less necessary to use the traditional excellent routing algorithms, such as Dynamic Source Routing (DSR)[6], Destination-Sequenced Distance Vector Routing (DSDV)[7], Ad-hoc On-demand Distance Vector Routing (AODV)[8], and other novel routing, protocols[9, 10, 11, 12, 13, 14, 15, 16, 17], which could greatly waste CPU com-
 20 puting resources of each node and cause too much overhead. Hence, for an incompletely predictable network, the corresponding lightweight algorithms are

required to be constructed. This paper can be divided into several main parts. Section 2 gives the related works. Section 3 interprets several important related concepts as well as the concept of “incompletely predictable networks”. In addition, we construct Model I to describe the network whose nodes are fixed as a specific topology and Model II to represent the network whose nodes move in a limited range around basic positions. Section 4 further elucidates the structure named Static Organized Topology (S-OT), and presents Static Organized Topology Based Routing (S-OTBR). After the description of the process of S-OTBR, we propose the concept of “anti-pheromone” referring to Ant Colony Optimization algorithm[18, 19], to maintain the network energy consumption equilibrium. Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is designed on the basis of “anti-pheromone”. Mainly aimed at discussing the situations where nodes move in certain ranges around the basic positions, Section 5 deeply parses Model II named Dynamic Organized Topology (D-OT). Besides, combined with greedy algorithm[20, 21], Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) is proposed to adapt the environment described by D-OT[22, 23]. In our simulation in Section 6, we figure out that APS-OTBR shows a reasonable node utilization frequency. Moreover, GrD-OTBR has a stable performance when network size changes and performs better in a relatively small size of the network. Last but not least, Section 7 records some improvement methods. In the view of the imbalance problem of area coverage frequency caused by node movement, we propose a concept of a equilateral triangle network structure. **Section 8 draws the conclusion.**

2. Related Works

Ad hoc networks are widely studied in recent decades. For instance, Delay Tolerant Networks (DTNs)[24], Wireless Sensor Networks (WSNs)[25], Vehicular Ad hoc Networks (VANETs) [26] are specific categories of Ad hoc networks. A large number of new protocols have been proposed in these fields. Tripp *et al.* [27] utilize the information retrieved by the sensors to make forwarding

decisions, which increases packet delivery ratio and decreases end-to-end delay. A real-time X-layer protocol is proposed by Mouradian *et al.* [28] to guarantee a bound on the end-to-end delay. Basurra *et al.* [29] utilize a one hop clustering algorithm splitting the network into zones by reliable leaders to achieve network stability and energy efficiency.

In this paper, OTBR is designed for incompletely predictable ad-hoc networks. OTBR is a general designation of routing protocols which are named as APS-OTBR and GrD-OTBR. APS-OTBR can be utilized into applications in which nodes are static, and GrD-OTBR can be applied to dynamic environment. The proposed protocols can be widely used in all aspects of real life, such as smart home, environmental monitoring, intelligent medical system, intelligent transportation and military defense.

3. Concepts and Models

3.1. Predictable Networks

Time-evolving and predictable networks are widely mentioned in DTNs[30] and WSNs[31, 32]. Fig. 1 illustrates an example of such time-evolving and predictable network. Fig. 1(a) shows the situation of the nodes and the link state of the network at the specific moment. Fig. 1(b) can be seen as a Time-Space graph which shows the locations of the nodes and the relationship between them in the form of a sequence of snapshot of the network. The concept of this kind of network is based on a theory that human mobility model can achieve a 93 percent potential predictability[33, 34].

3.2. Static Organized Topology (S-OT) Model (Model I)

Under the circumstances as is described with predictable networks, there is a specific situation that the positions of the nodes and the link status of the network are fixed. To simplify and present that, Model I named as Static Organized Topology (S-OT) is constructed.

In our first model, as shown in Fig. 2, nodes are orderly distributed in the test area (each intersection point has a node settled there), just like the layout

Figure 1: A time-evolving network: (a) a snapshot of the network, (b) time-evolving topologies of the network

of the chessboard. Nodes are fixed at the specified positions and attempt to
communicate with other nodes from time to time. The distances between every
two adjacent nodes are all the same, which can be represented as L . Clearly,
we can draw the first lemma.

LEMMA 1: The geographical locations of all nodes, which can be expressed
in coordinates, could be calculated with one location of a certain node in the
topology obtained by GPS.

3.3. Dynamic Organized Topology (D-OT) Model (Model II)

As stated earlier, there is still a 7 percent of human mobility that cannot
be accurately predicted[33]. In other words, the network related to human
mobility model is an incompletely predictable network. Dynamic Organized
Topology (D-OT) is designed to adapt such situation as Model II. The basic
structure of Model II is the same as Model I. The positions that the nodes are
settled at when the S-OT network is initialized are defined as Basic Positions

Figure 2: The model of S-OT network

Figure 3: A incompletely predictable ad-hoc networks

(BPs). What distinguishes D-OT from S-OT is that all nodes of D-OT move
 95 randomly around BPs in a limited range. In our simplified model of D-OT, the
 activity area of a node is a circular area whose center is BP and radius is R_{act} .
 According to the feature of Model II, we can draw LEMMA 2 by referencing
 LEMMA 1. Model II can be illustrated with time-space graph which is shown
 Fig. 3.

100 **LEMMA 2:** The geographical locations of the BPs of all nodes in Model
 II, which can be expressed in coordinates, could be calculated with one position
 of the BP of a certain node in the topology obtained by GPS.

As seen from Fig. 3, at the very beginning, nodes are set initially at the BPs.

At the following time slots, nodes move in the area near BPs. This is so-called
105 **the incompletely predictable ad-hoc networks** in our paper.

4. Static Organized Topology Based Routing Protocol

4.1. Overview of *S-OTBR*

In the fields of marine monitoring[35], meteorological monitoring[36] (such
as ground temperature monitoring[37], intelligent agriculture[38], etc.), fixed
110 nodes, evenly distributed in a certain area, might be required. Information in-
teraction and real-time monitoring of these nodes plays a very significant role in
such applications. For that reason, we propose an energy-efficient transmission
strategy that is suitable for the situations perfectly, which is named Static Orga-
nized Topology Based Routing (*S-OTBR*) Protocol. In **addition**, combined with
115 the concept of “anti-pheromone”, Static Organized Topology Based Routing us-
ing Anti-Pheromone (*APS-OTBR*) is proposed to achieve energy efficiency.

4.2. Static Organized Topology (*S-OT*) Model (Model I)

In order to simplify the problem, we first assume that the node transmis-
sion radius is equal to the distance between two adjacent nodes, which can be
120 expressed as $R_{trans} = L$. When it comes to the situation that the transmission
radius $R_{trans} = L$, a certain *S-D* pair indicates a certain length of the shortest
route(s) between the source and the destination. For example, as seen in Fig. 2,
assuming that the coordinates of *S* and *D* are $(L,0)$ and $(4L,4L)$, the shortest
route(s) for *S* and *D* to communicate with each other include 7 hops.

125 First of all, before node *S* communicates with *D*, *S* checks the topology
information to find the location of *D*. After having located *D*, *S* compares
its own ordination with that of *D* and makes the decision which direction it is
going to transmit the messages to. The implement of the transmission can be
described by the process in TABLE 1.

130 In TABLE 1, we use *right*, *left*, *up*, *down* and *same* to indicate the direc-
tions the node will transmit the messages to. Under the circumstance described

Table 1: Process of transmission initialization

Transmission initialization process of S-OTBR

```

Locate(S);
Locate(D);
if( $S.x < D.x$ )
    Mark right; //to mark the case that  $D$  is located at the right of  $S$ 
if( $S.x > D.x$ ) Mark left;
if( $S.x = D.x$ ) Mark same;
if( $S.y < D.y$ ) Mark up;
if( $S.y > D.y$ ) Mark down;
if( $S.y = D.y$ ) Mark same;

```

by Fig. 2, during the whole transmission process, the coordinate changing process of the transmitted message Msg can be represented as the process in Algorithm 1. Algorithm 1 describes the coordinate change process when the message
135 is marked as $\text{Msg} \langle \text{right}, \text{up} \rangle$. The horizontal or vertical ordinate of the message Msg increases by 1 each hop randomly until the coordinate of Msg is equal to that of D .

4.3. Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR)

140 In Ant Colony Optimization (ACO) algorithms, people define the concept of “pheromone” from natural phenomenon. The so-called “pheromone” gradually evaporates as time goes by. The value of pheromone indicates the characterization of path.

145 In our model, there is a series of routes which have the same length. What’s more, it is much easier for the network to figure out which routes are the shortest ones. Under these circumstances, “anti-pheromone” is designed to create a more energy efficient network and to achieve energy-balance through the entire network. Drawing on this concept, APS-OTBR is formed.

Algorithm 1 Routing by $\text{Msg} \langle \textit{right}, \textit{up} \rangle$ in S-OTBR

if the S - D pair is marked as *right* and *up* **then**

$\text{Msg}.x \leftarrow S.x$

$\text{Msg}.y \leftarrow S.y$

for $\text{Msg}.x! = D.x \parallel \text{Msg}.y! = D.y$ **do**

$\text{Msg}.x++ \parallel \text{Msg}.y++$

 //the coordinate changing process of Msg represents the transmission of
 message from S to D ;

end for

while $\text{Msg}.x! = D.x$ **do**

$\text{Msg}.x++$

end while

while $\text{Msg}.y! = D.y$ **do**

$\text{Msg}.y++$

end while

end if

To be specific, if the length of the route does not increase when the message
150 is sent to different neighbors, the node will choose a less used neighbor to relay
the message. Anti-pheromones of every neighbor are stored in the node. The
node which holds the message waiting to be transmitted compares the values
of its neighbors' anti-pheromones and choose the one with a lower value to be
the next hop. As seen in Algorithm 2, when a node n_i receives a RREQ packet,
155 it will firstly confirm whether the destination is the node itself. If it is not
the destination, the reception of RREQ indicates that node n_i is on one of the
shortest routes from S to D . When the node replies to the sender of the RREQ
with the ACK message, an information called APh is added to the ACK packet.
APh donates the value of anti-pheromone of the certain node. In other words,
160 APh represents how many times the node has been used to transmit messages
through the entire transport period.

The sender of the RREQ will pick up one node with the lowest value of APh
and send the message Msg to it. When a node receives a message packet, it will
perform the steps shown in Algorithm 3. The node checks the coordinate of the
165 message and constructs RREQ according to it. Secondly, the node multicasts
RREQ to those nodes who might be on the shortest routes from S to D . After
waiting for a proper period of time, it should have received ACKs from the
nodes who are ready to transport the Msg. The node will choose the optimal
next hop and unicast the message to it.

170 By using anti-pheromone, the network can figure out which nodes are used
the least number of times. The consumption of energy can be kept in balance
through the whole network.

5. Dynamic Organized Topology Based Routing Protocol

The S-OTBR makes sense in some applications as mentioned. However, S-
175 OTBR cannot flexibly dispatch nodes to transmit information. What's more,
there are some more complicated situations that cannot be abstracted by Model
I. Hence, we present a Dynamic Organized Topology (D-OT) model and propose

Algorithm 2 Upon receiving RREQ $\langle S, D \rangle$

```
if  $n_i == D$  then
    return RREP
else
    return ACK<Confirmation message, APh>
    //APh: the value of Anti-pheromone of the certain node
end if
```

Algorithm 3 Upon receiving Msg $\langle S, D, \text{data}, \text{Msg}.x, \text{Msg}.y \rangle$ from the other nodes

```
if  $n_i == D$  then
    The transport of this package is over.
else
    Locate( $S$ )
    Locate( $D$ )
    //obtain the coordinates of  $S$  and  $D$ 
     $\text{Msg}.x = n_i.x$ 
     $\text{Msg}.y = n_i.y$ 
    //evaluate the coordinate of Msg with the one of this node
    if  $\text{Msg}.x \neq D.x \parallel \text{Msg}.y \neq D.y$  then
        Multicast RREQ to those nodes who might on the shortest routes from
         $S$  to  $D$ ;
        Wait( $T$ )
        Receive ACK from the nodes who are ready to transport the Msg;
        if  $n_j == \text{Min}(\text{ACK.APh})$  then
             $\text{NextHop} == n_j$ 
            //find the next hop which has the minimal value of APh
        end if
        Unicast Msg to  $n_j$ 
    end if
end if
```

Dynamic Organized Topology Based Routing (D-OTBR) protocol to adapt to those situations that nodes move in a limited range. To obtain optimal routes, combining Greedy Algorithm with D-OTBR, we present Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) protocol.

5.1. Overview of D-OTBR

In practice, some network structures may have fixed borderlines to limit the activities of each node, for which the network can be regarded as fixed from a macro point of view. But individuals in the network, sending information to communicate with each other, may produce regular or irregular movement in the neighborhood of some fixed positions. For example, in the field of medical and health care[39, 40], or body area networks[41, 42], the locations of the hospital wards are relatively fixed, but the positions of information carriers on the patients and nurses are often incompletely predictable. Moreover, the ranges of their activity areas are limited. For instance, the relative position between the planets are stable for a long time, while the information transmission carriers between interstellar satellites[43] may move within a certain range. So, D-OT network is a kind of simplified MANET[44] and is also the specific model for those situations as mentioned.

5.2. The Probability of Transmission to Be Implemented

In the following parts, we are going to discuss the probability of transmission to be implemented successfully in the incompletely predictable ad-hoc network of Dynamic Organized Topology (D-OT).

5.2.1. With the same radius of activity range and transmission range (two nodes)

To further simplify the model, we first set the activity radius R_{act} as long as the transmission radius of the node as well as the distance between two adjacent nodes. In other words, $R_{act} = R_{trans} = L$ as shown in Fig. 4. Later, we will discuss the situation that R_{act} is not equal to R_{trans} .

Figure 4: The model of D-OT network

Our analysis begins with the communication situation of two nodes. As is shown in Fig. 5, node D_1 is not at BP but a position with a distance from BP, marked D'_1 .

We marked the BP of D_2 as BP_2 . The distance of these two nodes is $|D_1 D_2|$.
 210 If and only if $|D_1 D_2|$ is less than or equal to R_{trans} , D'_1 and D_2 can communicate with each other. It is easy to be proved that if and only if the node D_2 would appear in the shadow area, D'_1 can implement communication with D_2 . We use the following formulas Eqs. (1) $\sim$ (7) to calculate the probability of the situation that D_2 appears in the shadow area happens. The probability $P_{1 \rightarrow 2}$
 215 also represents the possibility that D_2 can receive the message sent by D'_1 .

$$R_{trans} = R_{trans} = R \quad (1)$$

$$\theta_1 = \theta_2 = \theta \quad (2)$$

$$x^2 + y^2 \leq R^2 \quad (3)$$

$$|D'_1 BP_2| = \sqrt{(x - R)^2 + y^2} \quad (4)$$

$$\theta = 2 \arccos \frac{|D'_1 BP_2|}{2R} \quad (5)$$

$$S = 2 \times \left(\frac{1}{2} R^2 \theta - \frac{1}{2} R^2 \sin \theta \right) = R^2 (\theta - \sin \theta) \quad (6)$$

$$P_{1 \rightarrow 2} = \frac{S}{\pi R^2} = \frac{\theta - \sin \theta}{\pi} \quad (7)$$

Figure 5: The communication situation of two nodes

The y-axis coordinate of D_1 is kept unchanged, to study the probability $P_{1 \rightarrow 2}$ as its x-axis coordinate changes, and accordingly Fig. 6 is drawn. $P_{1 \rightarrow 2}$ correlates positively with the horizontal ordinate of D_1 , which indicates that the shorter the horizontal distance of D_1 and BP_2 is, the larger the probability that D_2 can receive the message sent by D_1' is.

Fig. 7 is a line graph which describes the value of $P_{1 \rightarrow 2}$ changing with the distance of node D_1 from the x-axis. Conclusion can be drawn that, when the horizontal distance of D_1 and BP_2 does not change, the farther the node is from the x-axis, the lower the probability will be.

The probability that D_2 can receive the message sent by D_1' when D_1' is located in a random place whose distance from BP_1 is no more than R_{act} is calculated. We test nearly ten thousand positions in that area and get Fig. 8.

From Figs. 6, 7 and 8, we can draw the conclusion that the shorter the relative distance between D_1 and BP_2 is, the greater the probability that D_2 can receive the message sent by D_1' will be.

Figure 6: The relation between D_1 's x coordinate and $P_{1 \rightarrow 2}$

Figure 7: The relation between D_1 's y coordinate and $P_{1 \rightarrow 2}$

Figure 8: The relation between D_1 's coordinate and $P_{1 \rightarrow 2}$

Figure 9: The model of three nodes

5.2.2. *With the same radius of activity range and transmission range (numerous nodes)*

After considering the situation of two nodes, we take that of three nodes into consideration, vividly shown by Fig. 9.

The probability that the message of D_1' can be received by D_2 or D_3 is equal to the probability that D_2 or D_3 (or both of them) appears in the dash area in Fig. 8. The probability that D_3 can receive the message sent by D_1' is marked as $P_{1 \rightarrow 3}$. And the total probability $P_{1 \rightarrow 2/3}$ can be expressed as Eq. (8).

$$P_{1 \rightarrow 2/3} = 1 - (1 - P_{1 \rightarrow 2})(1 - P_{1 \rightarrow 3}) \quad (8)$$

To summarize, a equation that can express the situations of any numbers of nodes is given as Eq. (9).

$$P_{1 \rightarrow \forall} = 1 - \prod_{i=1}^n (1 - P_{1 \rightarrow i}) \quad (9)$$

235 $P_{1 \rightarrow \forall}$ represents the probability that the transmission is successfully completed, no matter which node receives the message sent by D_1 . With the increase of the number of nodes around the sender, the probability that the node could be heard continuously rises.

In Fig. 10, D_i at BP_i is one of the farthest nodes that can hear from D_1 ,
240 however, the probability is too low for us to consider it. So, we assume that no

Figure 10: The farthest node that might hear from D_1

Figure 11: The probability that D_1 could be heard with 8 nodes around it

nodes more than $3L$ away from BP_1 can still hear from D_1 . Hence, there are only 24 nodes could hear from D_1 in this case.

Nodes within $3L$ are divided into 2 groups in Fig. 10. We call the group of nodes on the green line in Fig. 10 the first round and that of nodes on the pink line the second round. Considering that the second round nodes have little things to do with the reception of message from D_1 , Fig. 11 indicates that even there are only the eight nodes of the first round in the network, the probability that D_1 is heard exceeds 93%.

By calculation, even at BP_1 , the position with the lowest possibility for D_1 to be heard, the probability can achieve more than 93.8%.

5.2.3. With different radii of activity range and transmission range

To make our model more similar to the real situation, we take another case into consideration. In this case, the radius of the activity range of D_1 is different from that of its transmission range and the distance between two adjacent nodes.

255 The model can be described as Fig. 12.

In this case, there are several changes in the calculation of the possibility that D_2 can receive the message sent by D'_1 , which is shown with Eqs. (10) ~ (15).

$$\theta_1 = 2 \arccos \frac{|D'_1 B P_2|^2 + R_{trans}^2 - R_{act}^2}{2|D'_1 B P_2| \times R_{trans}} \quad (10)$$

$$\theta_2 = 2 \arccos \frac{|D'_1 B P_2|^2 + R_{act}^2 - R_{trans}^2}{2|D'_1 B P_2| \times R_{act}} \quad (11)$$

$$S_1 = \frac{1}{2} R_{trans}^2 (\theta_1 - \sin \theta_1) \quad (12)$$

$$S_2 = \frac{1}{2} R_{act}^2 (\theta_2 - \sin \theta_2) \quad (13)$$

$$S = S_1 + S_2 = \frac{1}{2} [R_{trans}^2 (\theta_1 - \sin \theta_1) + R_{act}^2 (\theta_2 - \sin \theta_2)] \quad (14)$$

$$P_{1 \rightarrow 2} = \frac{S}{\pi R_{act}^2} = \frac{S}{2\pi} \left[\frac{R_{trans}^2}{R_{act}^2} (\theta_1 - \sin \theta_1) + (\theta_2 - \sin \theta_2) \right] \quad (15)$$

5.3. Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR)

The transmission probability which is discussed above is utilized to select the optimal relay node in GrD-OTBR detailed in this section. No matter in

260 what kind of networks, there excises a problem that due to the movement of nodes, the node might transmit messages to a path which is not the optimal one. The example shown in Fig. 13 describes a situation of that problem. The node S communicates with D through A and B when the node B is at the initial position which is red. After a very short period of time τ (τ represents the

Figure 12: The model of $R_{act} \neq R_{trans}$

Figure 13: An example of a more optimal path due to the movement of nodes

265 longest time for S to held the message without transmitting it to any nodes),
node B moves to the position B' which is blue. If the messages were transmitted
at this moment, the new path “ S - B' - D ” which has lower hops should be chosen.
This example indicates that without a proper waiting mechanism, many paths
that are not optimal will be chosen to transmit information.

270 According to LEMMA 2, if S knows the position of its own BP in Model II,
all the BPs of the other nodes could be calculated by itself, because of which S
could figure out the optimal alternative forwarder node which is closest to D .
We assume that every δ seconds, B appears in a new position. The probability
 S could be heard by B in a period of time τ can be expressed as P_τ . Eq. (16)

275 shows the calculation method of P_τ .

$$P_\tau = 1 - (1 - P_{A \rightarrow B})^{\lfloor \frac{\tau}{\delta} \rfloor} \quad (16)$$

As can be inferred from Eq. (16), with a fixed time δ , the longer time τ the node waiting for, the bigger the probability will be. Once the node B in the example shown in Fig. 13 is chosen to be the forwarder, the hop number will drop. However, due to the waiting time τ , the delay of this route might change.
 280 To utilize this feature and find out a proper optimization method[45], we propose a new algorithm named Greedy Algorithm Based Dynamic Organized Topology Based Routing (GrD-OTBR), which can be seen in Algorithm 4.

It is worth noting that, X in Algorithm 4, is a collection of all nodes that might have the chance to become the next hop to forward the message. Draw
 285 horizontal lines and vertical lines through node S and D , we can get a rectangular area R as shown in Fig. 14. In this paper, we define the nodes that can hear from S , and what's more, of which the BPs are in the area R as the elements in the collection X (which are green in Fig. 14).

In the actual transmission process, we introduce the concept of hello message
 290 to greedily select the optimal node. S will try to broadcast hello message to the seven green nodes in Fig. 14. Nodes receiving the hello message will obtain their current positions by GPS, calculate the current distance to the BP of D and feedback to S . After that, S will send the message to the node who is closest to the BP of D . By this means, the algorithm should have the ability to avoid
 295 link failure when some of the nodes on the way to the destination are dead or out of contact.

6. Performance Evaluation

Simulation and comparison among DSDV, DSR, AODV and our proposed protocol are implemented by utilizing ns-2 simulator. In our simulation we use
 300 the version ns-2.35 and run the protocols on Ubuntu 12.04.

Algorithm 4 GrD-OTBR Algorithm

$X \leftarrow$ all nodes that might have the chance to become the next hop
 $d \leftarrow 65535$
 $V \leftarrow$ the node chosen to be the next hop by the process in TABLE 1
while X **do**
 $n \leftarrow$ one of the nodes in X
 $X \leftarrow X - n$
 if $|SV_i| \leq R_{trans}$ **then**
 if $|DV_i| \leq R_{trans}$ **then**
 if $|DV_i| < d$ **then**
 $d \leftarrow |DV_i|$
 $V \leftarrow i$
 end if
 else
 return
 end if
 else
 return
 end if
end while

Figure 14: An example of nodes in X

In addition, running with the following parameters, we set proper test environments to simulate our protocol to figure out its performance. On the basis of Model II¹, we model 16(4×4), 49(7×7), 100(10×10) and 144(12×12) mobile nodes moving as Model II set in a square area. The moving speed of each node is uniformly distributed between 0~5 meters/sec. Standard two-ray ground propagation model is used in our simulation, both with the IEEE 802.11 MAC, and omni-directional antenna model in ns-2. Some of the significant parameters in our simulation are given in TABLE 2.

6.1. Performance Measurement

The algorithms proposed in this paper, which are named as Static Organized Topology Based Routing (S-OTBR) protocol, Static Organized Topology Based Routing using anti-pheromone (APS-OTBR) and Organized Topology Based Routing with greedy algorithm (GrD-OTBR), are evaluated to figure out the performance of these algorithms, comparing with several typical ad-hoc routing protocols such as DSR, DSDV and AODV. The environments of networks which are utilized in our simulations are not limited to the networks described by

¹In the first half of the simulation results, we calculate and simulate several metrics of S-OTBR and APS-OTBR, which are designed on the basis of Model I. Note here that Model I is static and has no need to be compared with conventional protocols in ns-2.

Table 2: Parameters used in simulation

Parameter	Value
Number of nodes	16, 49, 100, 144
Mac	IEEE 802.11 DCP
Traffic source	CBR for UDP-based traffic
Node speed	0~5m/s
Propagation model	Two-ray ground reflection
Simulation time	1000 seconds

Model I and Model II. The network environments tested in our simulations have the following characteristics:

- Limited number of nodes;
- Nodes are located at fixed positions which are called the Basic Positions (BPs);
- Nodes move in a limited range around the BPs if they are needed to.

To analyze our routing protocols, we take the following metrics as the performance measurements:

Node Utilization Distributing Equilibria Degree: we use the standard deviation of the number of times each node is used through the whole transmission process to evaluate whether the utilization of nodes is proper to achieve energy efficient and reasonable node utilization frequency. The degree can be calculated with Eq. (17) as follow:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}, \quad (17)$$

where N represents for the total number of nodes; x_i represents for the number of times node i is used; μ is the average of all the numbers of times each node is used.

What's more, we can also calculate the node utilization ratio of network to see whether our protocol can fully use the nodes through the whole network.

335 **Capacity of Handling Link Failure:** this metric aims to figure out the ability of S-OTBR and GrD-OTBR to deal with the situation that one node on the path from S to D has lost contact with other nodes.

We assume that all nodes who can hear from S in the first hop of transmission have the same chance to receive the message from S . In other words, $p_x = p_1 =$
 340 $p_2 = \dots = p_i$ (x represents that the transmission process has x hops for this moment, p_i represents for the probability a normal node n_i receives the message from S under the circumstance that the first step of transmission is successful). The metric capacity of handling link failure can be represented by calculating the possibility a message is transmitted successfully through the whole transmission
 345 process with Eq. (18),

$$P_m = 1 - P_{m-1} \times p_{m-1} \sum_i (1 - P_{n_i}), \quad (18)$$

where m is the total number of hops through the whole transmission process; $\sum_i (1 - P_{n_i})$ is the sum of probabilities of failure delivery caused by nodes that might hold the message in this hop due to the dead or being out of contact of nodes in the following hops. In the first hop, the probability P_1 is calculated with
 350 Eq. (9), representing for the probability of message successfully being received by any node. It is worth noting that the concept of any node means the node which is needed when transmission, in other words, means the node in green in Fig. 14, when it comes to GrD-OTBR.

Packet Delivery Ratio: The definition of packet delivery ratio is given
 355 by Eq. (19).

$$\begin{aligned} \text{Packet delivery ratio} = \\ \frac{\text{Number of delivered packets}}{\text{Number of generated packets}} \end{aligned} \quad (19)$$

Normalized Routing Overhead: The expression to figure out normalized

routing overhead is shown in Eq. (20).

$$\begin{aligned} \text{Normalized routing overhead} = \\ \frac{\text{Number of routing packet transmission}}{\text{Number of data packet transmission}} \end{aligned} \quad (20)$$

Average End-to-end Delay: The representation of average end-to-end delay is described in Eq. (21).

$$\begin{aligned} \text{Average end-to-end delay} = \\ \text{Average value of} \\ (\text{delivered packets' time stamp} - \\ \text{generated packets' time stamp}) \end{aligned} \quad (21)$$

360 To sum up, we will discuss the performance of the protocols proposed in this paper in node utilization distributing equilibria degree, capacity of handling link failure, packet delivery ratio, normalized routing overhead and average end-to-end delay.

6.2. Results and Discussion

365 6.2.1. Node Utilization Distributing Equilibria Degree

We set five different sizes of network structure. Comparing the value of σ and the utilization ratio of S-OTBR and APS-OTBR, we come to the conclusion that anti-pheromone is indeed effective in balancing the frequency of the node utilization in the network.

370 From the data in TABLE 3, we can come to the conclusion that, APS-OTBR is better than S-OTBR in controlling node usage frequency, which can better use the node information to select more effective paths, and complete the whole information transmission process without laying excessive concentration on using a part of the nodes.

375 In addition, the choices of S - D pairs have a great influence on the use of nodes. For example, in the situation where network structure has 3×3 nodes, the random selections of S - D pairs are too concentrated, resulting in relatively

large Node Utilization Distributing Equilibria Degree. But even in this case, APS-OTBR can still do the best possible to balance the utilization of nodes in order to achieve better results. We also find that the effect of APS-OTBR will perform better transmission when S and D are separated far away from each other, no matter from the view of the horizontal or vertical coordinates.

Table 3: Performance in node utilization distributing equilibria degree

Protocols	S-OTBR		APS-OTBR	
Metrics	σ	utilization ratio	σ	utilization ratio
3×3 nodes	3.281072	100%	2.054805	100%
4×4 nodes	1.561249	81.25%	1.346291	81.25%
5×5 nodes	2.465766	100%	1.385641	100%
6×6 nodes	3.854911	86.11%	1.554315	100%
7×7 nodes	4.389226	89.80%	1.399708	100%

Thanks to the feature of APS-OTBR to choose nodes that have been used less or even never been used as a matter of priority, under the premise of considering the optimal path, the node utilization rate remains at a relatively high level. However, by using S-OTBR, it is easier to have such a situation that some nodes have been used over and over again while others have not been used for some time. The excessive concentrated selection of S - D pairs will also result in the neglect of some of the nodes. Even APS-OTBR cannot completely solve this problem as is shown in the case of 4×4 network structure. But with the increase in the number of network utilization, things will get better.

6.2.2. Capacity of Handling Link Failure

To measure this metric, which can demonstrate the performance of proposed protocols when there exist some dead nodes or some unable to contact at that moment, we set the following four scenarios shown in Fig. 15. In the absence of link failure feedback messages, we simulate and figure out the probabilities of S-OTBR and GrD-OTBR of successful delivery and the proportion of the selected routes with less than three hops from all the possible routes.

It is clear from TABLE 4 that, without link failure feedback, S-OTBR has
400 very low delivery rates. GrD-OTBR has no need to know whether there are any
dead nodes in the following candidate nodes, for which GrD-OTBR performs
well. In our proposed protocol, nodes just need to focus on whether there are
proper nodes who can hear from it. The number of candidate nodes and the
state of them are not taken into consideration unless all of the candidate nodes
405 are dead or out of contact in the same time, which is generally not going to
happen.

The total hop number of S-OTBR is a fixed value as 7 in the scenarios we
set in the simulation. Nevertheless, GrD-OTBR avoids this defect, for large
probability of being heard by more nodes. Viewed from TABLE 4, the prob-
410 ability that the number of hops is lower than 3 can reach approximately 50%,
which indicates that the DrD-OTBR protocol can achieve good performance of
delivering messages as well as keeping a very low overhead and relatively saving
more time on transmitting messages from node to node.

Table 4: Capacity of handling link failure

Protocols	S-OTBR	GrD-OTBR	
Metrics	P_m	P_m	num of hops ≤ 3
Scenario 1	49.92%	82.38%	57.43%
Scenario 2	51.01%	97.81%	50.50%
Scenario 3	75.26%	97.69%	53.38%
Scenario 4	62.52%	97.09%	47.09%

6.2.3. Effect of Node Density

415 Node density is considered in the fixed-size network. On the basis of Model
II, we set 16 nodes(4×4), 49 nodes(7×7), 100 nodes(10×10) and 144 nodes(12×12)
in a fixed topology according to their moving ranges and transmission ranges.
We take packet delivery ratio, normalized routing overhead and average end-
to-end delay as the parameters of Y axis. We put the line of the data of each

(a)

(b)

(c)

(d)

Figure 15: Scenarios of link failure: (a) Scenario 1: node (1,0) is dead; (b) Scenario 2: node (1,1) is dead; (c) Scenario 3: node (0,2) is dead; (d) Scenario 4: node (1,2) is dead

parameter of DSDV, DSR, AODV and GrD-OTBR in to the same figure as follow. Fig. 16 show the line charts.

As shown in Fig. 16(a), as the node density increases, the packet delivery ratio of AODV routing protocol increases gradually. The performances of DSDV and DSR are good when the number of nodes is neither too big nor too little. However, packet delivery ratio of GrD-OTBR floats in a certain range with a high value, but perform relatively better when the size of network is not so big, and the performance remains stable when the network becomes larger.

Vividly shown in Fig. 16(b), because of the need to obtain the node location, and the use of greedy algorithm to find out the proper object to deliver data packets, the overhead of GrD-OTBR is relatively larger in the acceptable range than AODV. But we still find that the performance of GrD-OTBR in this aspect is better when the size of the network is relatively small. Simulation data of normalized routing overhead of our protocol is very close to DSR. The performance of DSDV is not good in the view of overhead for the great cost on remaining routing table. The proposed protocol can calculate the whole topology of Basic Positions of nodes according to its own initial position and has no need to store and transmit routing table.

Viewed from Fig. 16(c), thanks to the reference to the strategy of “hello message”, the network performance of our protocol is good in the view of average end-to-end delay. In most cases, the delay of our protocol is lower mainly because the utilization of the greedy transmission strategy based on probability. Due to routing information stored in routing table, DSDV has a lower delay value than DSR.

7. Improvement Method

In the whole network, some of the area might be visited by a lot of nodes, but some area may not. That might cause the imbalance problem of area coverage frequency.

In Fig 17(a), in order to make sure that every place of the area in the square

(a)

(b)

(c)

Figure 16: Performance versus node density: (a) packet delivery ratio; (b) normalized routing overhead; (c) average end-to end delay

Figure 17: The overlapping area while nodes move in the network

shaped by 4 nodes can be visited by nodes, we set the radii of the nodes' activity
 450 range as $\frac{\sqrt{2}}{2}L$. But even in that case shown in Fig. 17(a), there are still 4 parts
 which may be visited by two nodes while other parts can only be visited by one.
 For that reason, in our further work, we decide to construct a topology that is
 based on equilateral triangles, which is shown in Fig. 17(b).

By calculation, the overlap sections account for 57.08% of the whole square
 455 area, while the percentage drop to 20.92% in the case of equilateral triangle.
 Overlapping area is reduced by more than half of the whole network area, if we
 expand the single area to the entire network. We believe that combined with
 the new presented concept of equilateral triangle topology, protocols will show
 better performance in node utilization frequency.

460 8. Conclusion

In this paper, we propose Organized Topology Based Routing (OTBR), a
 general designation of routing protocols designed for incompletely predictable
 ad-hoc networks that the structure is fixed or relatively stable from the macro
 view but actually dynamic from the micro perspective. Firstly, the model of
 465 Static Organized Topology (S-OT) is discussed, where no nodes can move and
 are all settled at the Basic Positions. Static Organized Topology Based Routing

(S-OTBR) protocol is proposed. Combined with “anti-pheromone”, Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is presented. S-OT and APS-OTBR can be considered as the basis of our newly proposed protocol. Secondly, in the model of Dynamic Organized Topology (D-OT), nodes can move away from the Basic Positions in a limited range. In order to better utilize our protocol to this environment, Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) protocol is designed, whose performance node density has little influence on. Through our simulation, we figure out that our protocol GrD-OTBR performs well when node density changes especially in small size network. In addition, a more efficient topology composed by equilateral triangles is proposed.

Acknowledgments

This work is supported by the National Science Foundation of China under Grant No. 61300237, No. U1536206, No. U1405254, No. 61232016 and No. 61402234, the National Basic Research Program 973 under Grant No. 2011CB311808, the Natural Science Foundation of Jiangsu province under Grant No. BK2012461, the research fund from Jiangsu Technology & Engineering Center of Meteorological Sensor Network in NUIST under Grant No. KDXG1301, the research fund from Jiangsu Engineering Center of Network Monitoring in NUIST under Grant No. KJR1302, the research fund from Nanjing University of Information Science and Technology under Grant No. S8113003001, the 2013 Nanjing Project of Science and Technology Activities for Returning from Overseas, the 2015 Project of six personnel in Jiangsu Province under Grant No. R2015L06, the CICAET fund, and the PAPD fund.

References

- [1] T. Dutta, Medical data compression and transmission in wireless ad hoc networks, *IEEE Sensors Journal* 15 (2) (2015) 118–173. doi:10.1109/JSEN.2014.2354394.

- 495 [2] T. Shu, M. Krunz, Privacy-preserving and truthful detection of packet dropping attacks in wireless ad hoc networks, *IEEE Transactions on Mobile Computing* 14 (4) (2015) 813–828. doi:10.1109/TMC.2014.2330818.
- [3] C. Liu, J. Wu, Routing in a cyclic mobispace., *Mobihoc* 5346 (1) (2008) 351–360. doi:10.1145/1374618.1374665.
- 500 [4] J. Monteiro, A. Goldman, A. Ferreira, Performance evaluation of dynamic networks using an evolving graph combinatorial model, in: *IEEE International Conference on Wireless & Mobile Computing*, 2006, pp. 173–180. doi:10.1109/WIMOB.2006.1696378.
- [5] H. Chen, K. Shi, Topology control for predictable delay-tolerant networks based on probability, *Ad Hoc Networks* 24 (3) (2015) 147159. doi:10.1016/j.adhoc.2014.08.014.
- 505 [6] D. B. Johnson, D. A. Maltz, Dynamic source routing in ad hoc wireless networks, in: *Mobile Computing*, 1996, pp. 153–181. doi:10.1007/978-0-585-29603-6_5.
- [7] C. E. Perkins, P. Bhagwat, Highly dynamic destination-sequenced distance-vector routing (dsv) for mobile computers, *Acm Sigcomm Computer Communication Review* 24 (4) (1999) 234–244. doi:10.1145/190314.190336.
- [8] C. E. Perkins, E. M. Royer, Ad-hoc on-demand distance vector routing, *Proc.of IEEE Wksp.mobile Comp.sys. & Apps* 6 (7) (1999) 90–100. doi:10.1109/MCSA.1999.749281.
- 515 [9] S. Ping, A. Aijaz, O. Holland, A. H. Aghvami, Sacrp: A spectrum aggregation-based cooperative routing protocol for cognitive radio ad-hoc networks, *IEEE Transactions on Communications* 63 (6) (2015) 2015–2030. doi:10.1109/TCOMM.2015.2424239.
- 520 [10] U. Ghosh, R. Datta, Sdrp: secure and dynamic routing protocol for mobile ad-hoc networks, *Networks Iet* 3 (3) (2014) 235–243. doi:10.1049/iet-net.2013.0056.

- [11] C. M. Huang, S. Y. Lin, Timer-based greedy forwarding algorithm in vehicular ad hoc networks, *Iet Intelligent Transport Systems* 8 (4) (2013) 333–344. doi:10.1049/iet-its.2013.0014.
- [12] H. Shen, Z. Li, C. Qiu, A distributed three-hop routing protocol to increase the capacity of hybrid wireless networks, *IEEE Transactions on Mobile Computing* 14 (10) (2009) 277–284. doi:10.1109/TMC.2015.2388476.
- [13] Z. Wang, Y. Chen, C. Li, Psr: A lightweight proactive source routing protocol for mobile ad hoc networks, *IEEE Transactions on Vehicular Technology* 63 (63) (2014) 859–868. doi:10.1109/TVT.2013.2279111.
- [14] Shivashankar, H. N. Suresh, G. Varaprasad, G. Jayanthi, Designing energy routing protocol with power consumption optimization in manet, *IEEE Transactions on Emerging Topics in Computing* 2 (2) (2014) 192–197. doi:10.1109/TETC.2013.2287177.
- [15] L. Bello, P. Bakalis, P. Rapajic, K. A. Anang, Optimised adaptive power on-demand routing protocol for mobile ad hoc wireless network, *Networks Iet* 3 (4) (2014) 245–251. doi:10.1049/iet-net.2012.0115.
- [16] X. Jin, R. Zhang, J. Sun, Y. Zhang, Tight: A geographic routing protocol for cognitive radio mobile ad hoc networks, *IEEE Transactions on Wireless Communications* 13 (8) (2014) 4670–4681. doi:10.1109/TWC.2014.2320950.
- [17] N. Xiong, X. Jia, L. T. Yang, A. V. Vasilakos, Y. Li, Y. Pan, A distributed efficient flow control scheme for multirate multicast networks, *IEEE Transactions on Parallel & Distributed Systems* 21 (9) (2010) 1254–1266. doi:10.1109/TPDS.2010.29.
- [18] P. Gu, C. Xiu, Y. Cheng, J. Luo, Adaptive ant colony optimization algorithm, in: *Mechatronics and Control (ICMC), 2014 International Conference on*, 2014, pp. 95–98. doi:10.1109/ICMC.2014.7231524.

- 550 [19] J. W. Lee, J. J. Lee, Ant-colony-based scheduling algorithm for energy-efficient coverage of wsn, *IEEE Sensors Journal* 12 (10) (2012) 3036–3046. doi:10.1109/JSEN.2012.2208742.
- [20] K.-Y. Lin, P.-C. Wang, T.-P. Hong, A greedy algorithm in wsns for maximum network lifetime and communication reliability, in: *Networking, Sensing and Control (ICNSC)*, 2015 IEEE 12th International Conference on, 555 IEEE, 2015, pp. 87–92. doi:10.1109/ICNSC.2015.7116015.
- [21] H. A. de Oliveira, A. Boukerche, D. L. Guidoni, E. F. Nakamura, R. A. Mini, A. A. Loureiro, An enhanced location-free greedy forward algorithm with hole bypass capability in wireless sensor networks, *Journal of Parallel and Distributed Computing* 77 (2015) 1–10. doi:10.1016/j.jpdc.2014. 560 10.007.
- [22] P. Guo, J. Wang, B. Li, S. Lee, A variable threshold-value authentication architecture for wireless mesh networks, *Journal of Internet Technology* 15 (6) (2014) 929–936.
- 565 [23] P. J. Wan, C. W. Yi, F. Yao, X. Jia, Asymptotic critical transmission radius for greedy forward routing in wireless ad hoc networks, *Mobihoc Proceedings of Acm International Symposium on Mobile Ad Hoc Networking & Compu* 57 (5) (2006) 25–36. doi:10.1145/1132905.1132909.
- [24] J. Shen, S. Moh, I. Chung, X. Sun, Buffer scheme optimization of epidemic 570 routing in delay tolerant networks, *Journal of Communications & Networks* 16 (6) (2014) 656–666. doi:10.1109/JCN.2014.000112.
- [25] T. M. Rahayu, S. G. Lee, H. J. Lee, A secure routing protocol for wireless sensor networks considering secure data aggregation, *Sensors* 15 (7) (2015) 15127–15158.
- 575 [26] T. Taleb, M. Ochi, A. Jamalipour, N. Kato, An efficient vehicle-heading based routing protocol for vanet networks, in: *IEEE Wireless Communications & Networking Conference*, 2015, pp. 2199–2204.

- [27] C. Tripp-Barba, L. Urquiza-Aguiar, I. M. Aguilar, D. Rebollo-Monedero, D. L. C. L. Lj, A. M. Mezher, J. A. Aguilar-Caldern, A multimetric, map-aware routing protocol for vanets in urban areas, *Sensors* 14 (2) (2014) 2199–224.
- [28] A. Mouradian, I. Aug-Blum, F. Valois, Rtxp: A localized real-time mac-routing protocol for wireless sensor networks , *Computer Networks* 67 (10) (2014) 43–59.
- [29] S. S. Basurra, M. D. Vos, J. Padget, Y. Ji, T. Lewis, S. Armour, Energy efficient zone based routing protocol for manets, *Ad Hoc Networks* 25 (2015) 16–37.
- [30] J. Shen, S. Moh, I. Chung, A priority routing protocol based on location and moving direction in delay tolerant networks, *IEICE Transactions on Information and Systems* 93 (10) (2010) 2763–2775.
- [31] B. Zeng, Y. Dong, An improved harmony search based energy-efficient routing algorithm for wireless sensor networks, *Applied Soft Computing* 41 (2016) 135–147.
- [32] J. Shen, S. Moh, I. Chung, Comment: “enhanced novel access control protocol over wireless sensor networks”, *IEEE Transactions on Consumer Electronics* 56 (3) (2010) 2019–2021. doi:10.1109/TCE.2010.5606360.
- [33] C. Song, Z. Qu, N. Blumm, A. L. Barabsi, Limits of predictability in human mobility, *Science* 327 (5968) (2010) 1018–1021.
- [34] Z. Pan, Y. Zhang, S. Kwong, Efficient motion and disparity estimation optimization for low complexity multiview video coding, *IEEE Transactions on Broadcasting* 61 (2) (2015) 1–1. doi:10.1109/TBC.2015.2419824.
- [35] K. Murphy, T. Sullivan, B. Heery, F. Regan, Data analysis from a low-cost optical sensor for continuous marine monitoring, *Sensors and Actuators B: Chemical* 214 (2015) 211–217. doi:10.1016/j.snb.2015.02.023.

- [36] B. Wang, P. Zhang, G. Xiong, Farmland meteorological information monitoring system based on gprs, *Journal of Agricultural Mechanization Research*.
- [37] T. A. Hammer, W. L. Ryan, W. L. Zirjacks, Ground temperature observations, in: *Thermal Design Considerations in Frozen Ground Engineering*, 2010, pp. 8–52.
- [38] N. Rajput, N. Gandhi, L. Saxena, Wireless sensor networks: Apple farming in northern india, in: *Fourth International Conference on Computational Intelligence & Communication Networks*, 2012, pp. 218–221. doi:10.1109/CICN.2012.210.
- [39] P. M. Papazoglou, T. I. Laskari, G. K. Furlas, Towards a low cost open architecture wearable sensor network for health care applications, in: *Proceedings of the 7th International Conference on Pervasive Technologies Related to Assistive Environments*, 2014, pp. 1–8. doi:10.1145/2674396.2674404.
- [40] N. Xiong, A. V. Vasilakos, L. T. Yang, L. Song, Y. Pan, R. Kannan, Y. Li, Comparative analysis of quality of service and memory usage for adaptive failure detectors in healthcare systems, *IEEE Journal on Selected Areas in Communications* 27 (4) (2009) 495–509. doi:10.1109/JSAC.2009.090512.
- [41] J. Shen, H. Tan, S. Moh, I. Chung, Enhanced secure sensor association and key management in wireless body area networks, *Communications & Networks Journal* 17 (5) (2015) 453–462. doi:10.1109/JCN.2015.000083.
- [42] S. Misra, S. Moulik, H. C. Chao, A cooperative bargaining solution for priority-based data-rate tuning in a wireless body area network, *IEEE Transactions on Wireless Communications* 14 (5) (2015) 2769–2777. doi:10.1109/TWC.2015.2393303.
- [43] D. G. Messerschmitt, *Interstellar communication: The case for spread*

spectrum, *Acta Astronautica* 81 (1) (2012) 227–238. doi:10.1016/j.actaastro.2012.07.024.

- [44] J. Shen, H. Tan, J. Wang, J. Wang, S. Lee, A novel routing protocol providing good transmission reliability in underwater sensor networks, *Journal of Internet Technology* 16 (1) (2015) 171–178. doi:10.6138/JIT.2014.16.1.20131203e.
- [45] J. Li, X. Li, B. Yang, X. Sun, Segmentation-based image copy-move forgery detection scheme, *IEEE Transactions on Information Forensics & Security* 10 (3) (2015) 507–518. doi:10.1109/TIFS.2014.2381872.

Biographies

Jian Shen received the B.E. degree from Nanjing University of Information Science and Technology, Nanjing, China in 2007 and the M.E. and Ph.D. degrees in Computer Science from Chosun University, Gwangju, Korea in 2009 and 2012, respectively. Since late 2012, he has been a Full Professor in the School of Computer and Software at Nanjing University of Information Science and Technology, Nanjing, China. His research interests include computer networking, security systems, mobile computing and networking, ad-hoc networks and systems, and ubiquitous sensor networks.

Chen Wang will receive the B.E. degree in 2016 and is currently working toward the M.E. degree at Nanjing University of Information Science and Technology, Nanjing, China. He focuses on directional antennas in ad-hoc network. His research interests include ad-hoc networks and systems, and wireless sensor networks.

660

665

Anxi Wang will receive the B.E. degree in 2016 and is currently working toward the M.E. degree at Nanjing University of Information Science and Technology, Nanjing, China. He focuses on energy efficient routing protocols in wireless sensor network. His research interests include ad-hoc networks and systems, and wireless sensor networks.

670

675

Xingming Sun received the B.S. degree from Hunan Normal University, Changsha, China in 1984, the M.S. degree in Computer Science from Dalian University of Science and Technology, Dalian, China in 1988, and the Ph.D. degree in Computer Science from Fudan University, Shanghai, China in 2001. Since 2011, he has been the Dean of the School of Computer and Software, Nanjing University of Information Science and Technology and the Director of Jiangsu Provincial Center for Network Security Engineering. His research interests include network and information security, cloud computing, wireless sensor networks, and information hiding.

680

685

Sangman Moh received the Ph.D. degree in Computer Engineering from Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea in 2002. Since late 2002, he has been a Faculty Member in the School of Computer Engineering at Chosun University, Gwangju, Korea. From 2006 to 2007, he was on leave at Cleveland State University, Cleveland, Ohio, USA. His research interests include mobile computing and networking, ad hoc networks

690

and systems, ubiquitous sensor networks, network based computing, parallel and distributed computing, and high-performance computer systems.

695

700

Patrick C. K. Hung is an Associate Professor at the Faculty of Business and Information Technology in University of Ontario Institute of Technology, Canada. Patrick has been working with Boeing Research and Technology on aviation services-related research with two U.S. patents on mobile network dynamic workflow system. He is an Honorary International Chair Professor at National Taipei University of Technology in Taiwan, an Adjunct Professor at Nanjing University of Information Science & Technology in China, and a Visiting Professor at University of Sao Paulo in Brazil. Before that, he was a Research Scientist with Commonwealth Scientific and Industrial Research Organization in Australia as well as he worked as a software engineer in industry in North America. He is a founding committee member of the IEEE International Conference of Web Services (ICWS), IEEE International Conference on Services Computing (SCC), and IEEE BigData Congress (BigData Congress). He is also an Associate Editor of the IEEE Transactions on Services Computing, and a Coordinating Editor of the Information Systems Frontiers.

710