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An energy-efficient cooperative multicast routing in multi-hop wireless networks for smart medical applications

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ABSTRACT

With the advance of multimedia and pattern recognition based medical technologies, smart medical applications in smart hospital and smart medical for individual, such as disease diagnosis and health monitoring, play an important role in our life. However, the communication infrastructure of supporting these applications is a challenge. This paper studies the energy-efficient multicast routing problem in multi-hop wireless networks for these medical applications. Energy consumption has become the main problem of sustainable development of communication networks, particularly for these applications. How to carry out high energy-efficient communication is an important research topic for wired and wireless networks to implement green communications. This paper proposes an energy-efficient multicast routing approach to multi-hop wireless networks for smart medical applications. Different from previous methods, we aim at maximizing energy efficiency of networks. To this end, we make use of topology control and sleeping mechanism to obtain the optimal routing strategy with maximum network energy efficiency to construct the network multicast route. Simulation results show that the proposed approach is effective and feasible.

1. Introduction

With the advance of multimedia and pattern recognition based medical technologies, smart medical applications in smart hospital, smart clinic, and smart medical, such as disease diagnosis and health monitoring, play an important role in our life and are paid extensive attentions to. However, the communication infrastructure of supporting these applications is facing a larger challenge. This paper studies the energy-efficient routing problem in multi-hop wireless networks for these medical applications [1,2]. For the applications such as network security and cloud computing [3–5], the high energy consumption has an important impact on network performance of multi-hop wireless networks. Moreover, the energy and transmission power of nodes can directly affect network connectivity and survivability [6,7]. The high energy-efficient communication has become a hot topic [8–10]. Thereby, how to achieve high energy-efficient communication in multi-hop wireless networks is an important challenge [11,12]. This also has a significant affection on other applications as mentioned in [13–16]. Therefore, high energy-efficient communications have received extensive attention from network researchers and operations [17,18].

Bordón studied the energy-efficient power allocation problem in cooperative cognitive radio networks [2]. Dewangan et al. investigated the cooperative energy-efficient broadcast tree problem with the maximum lifetime in the multi-hop wireless network [12]. Han et al. studied a shared multicast tree construction problem spanning member nodes in static wireless networks to obtain the efficient group communication [17]. Additionally, some multi-hop network protocols had enhanced network performance via cooperative communications [6]. Su et al. [11] proposed an asynchronous wake-up scheme based on combinatorial designs to minimize the working duty cycle of sensor nodes. If no topology control, network node can maximize transmission power to communicate with each other. This can also lead to stronger interference between nodes. Many existing studies rarely consider energy consumption of receiving nodes in multicast multi-hop wireless networks [7]. However, the energy consumption of receiving nodes is inevitable such as applications mentioned in Refs. [19–22]. Thereby, some researchers have studied the sleeping mechanism to reduce energy consumption of networks [18,23,24]. Through sleeping, one can let more links or nodes stay sleeping with the result that the whole network consumes much lower energy than normal operation. This is helpful to achieve energy saving for applications as mentioned in Refs. [25–27]. However, the multicast routing methods in multi-hop wireless networks, on the one hand, only take into account multicast throughput while they cost more network energy consumption; in such a case, they assume that network nodes can be

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provided with infinite energy to guarantee continuous power transmission. It is not able to implement these because they add a large amount of carbon emission and networks such as ad hoc and wireless sensor networks can hardly supply continuous energy to achieve the ideal communications. On the other hand, although some methods study the saving energy approaches to reduce energy consumption of networks, they only target the minimum energy consumption or regard nodes' transmission power as constraints; to a certain extent, these methods can improve networks' high energy consumption problem while they only take in consideration network performance or network energy consumption [28,29]. As a result, it is significantly difficult to use these approaches to achieve the high energy-efficient communication in multi-hop wireless networks.

In this paper, we study the energy-efficient multicast routing problem in multi-hop wireless networks with finite energy provision, such as multi-hop ad hoc networks, multi-hop sensor networks, and multi-hop cellular networks, which is used for smart medical applications. Instead of aiming at a certain special networks, we want to explore a energy-efficient multicast approach suited for universal multi-hop wireless networks with infinite and finite energy supply. We propose a Topology control and Cooperation based Energy-efficient Multicast routing (TCEM) approach to achieve better network performance for multi-hop wireless networks. We take advantage of the periodical and alternative sleep of network nodes to reduce the network consumption and thereby improve network energy efficiency. Our approach utilizes a reasonable sleeping scheme to make nodes work alternately, and it can make use of the energy more efficiently under the premise of not affecting the normal operation of the network. Through the combination of this sleep mechanism and the minimum energy consumption multicast routing algorithm (TPM) based on topology control, we can significantly reduce the energy consumption of multicast and improve network energy efficiency. Simulation results show that compared to the existing methods, the algorithm proposed has better energy efficiency and performance improvement.

The remainder is organized as follows. Section 2 introduces related work. In Section 3 we describe the network model and perform problem statement. Section 4 discuss our channel allocation method. Section 5 conducts the numerical experiments and analysis. We conclude our work in Section 6.

2. Related work

The cooperation among network nodes can effectively improve network performance, such as data delivery in nodes-intensive sensor networks with finite energy provision. The energy efficiency has been become an import metric for network performance. The energy efficient and cooperative networking has received the extensive attention.

Tavli et al. integrated and reengineered the tree and mesh structures to achieve the energy-efficient multicast communication in mobile Ad Hoc networks [30]. Kao et al. studied the energy efficiency problem in video multicast [31]. Dabbagh et al. studied cloud computing problem with high energy efficiency [32]. Das et al. exploited fuzzy logic to choose the path with minimum energy consumption of nodes [33]. Feng et al. reviewed the energy-efficient methods in wireless networks [34]. Ge et al. presented an energy-efficient optimization approach to improve the MIMO-OFDM mobile multimedia communication systems [35]. Yang et al. proposed an adaptive sleeping scheme to raise energy efficiency performance of networks [36]. Irwin et al. investigated the energy-efficient architecture in multi-hop communications [37]. Zhang et al. proposed an energy-efficient routing protocol to achieve energy-efficient communications in vehicle connected networks [38]. Different from these methods, we sufficiently adopt the idea of the cross-layer design. Our approach integrates cooperative transmission in physical layer, cluster in MAC layer, multicast routing in network layer, and multi-node decoding in physical layer. We put forward the cooperative transmission strategies and provide reliable transmission link for multi-hop communications in wireless networks.

Additionally, the cooperation among network nodes is helpful to guarantee reliable connection of networks [24]. Each node uses the fixed transmission power and first conducts clustering and then proceed data transmission [28]. Shi et al. proposed a two-phase cooperative multicast communication method to maximize energy efficiency of networks [29]. The cooperative communication is taken into consideration by many topology control protocols [39–41]. Zhu et al. proposed two kinds of topology control algorithms, and the two algorithms used the idea of cooperative communication to construct the energy-efficient path [41]. Different from these method, our method firstly construct the multicast tree. Then through topology control, we perform the clustering process and cooperation of nodes. In this way, we can avoid the waste caused by the enormous computational overhead of clustering in advance.

Due to advantages of cooperative communications in energy conservation and increase of network coverage area, Li et al. proposed an energy-efficient cooperative relaying approach in unmanned aerial vehicle networking [42]. Maitya et al. studied the energy-efficient cooperative spectrum sensing approach in cognitive networks [43]. However, even though these algorithms can conserve energy at a certain degree, it cannot become more energy-efficient for the entire network. Therefore, we use topology control and sleeping mechanism to establish a new highly energy-efficient path for the multi-hop wireless network.

3. System model and problem statement

Next, we discuss the system model for energy-efficient cooperative multicast routing in multi-hop wireless networks and perform the relative problem statement.

3.1. Transmission model

In multi-hop wireless networks, when the Signal Noise Ratio (SNR) of the received signal for each node is only sufficiently high, the nodes can communicate with each other correctly. The link construction depends on the following factors: distance among nodes, transmission power of nodes, interference among nodes, and noise. Generally, the interference among nodes can importantly affect the performance of multi-hop wireless networks, such as energy consumption, network connectivity, and data delivery efficiency. Without loss of generality, assume that there exists F channels used for data transmission and these channel can be multiplexed over the time. In such a case, different nodes can use different channels at the different times according to data delivery requirements. Beside, this can effectively avoid the interference among nodes.

For build the reliable connection, the received signal power $p_s d^{-\alpha}$ of a receiving node is satisfied with $p_s d^{-\alpha} \geq \delta$, where p_s is the transmission power of transmission node s, d denotes the distance between the sending and receiving nodes, δ represents the noise, and α is a parameter value between 2 and 4. Fig. 1 shows the transmission model used in this paper, where s is the source node, i and j are two destination nodes. According to the constraints, if nodes i and j want to receive reliably the signal of node s, the minimum transmission power of node s to nodes i and j is, respectively, p_{si} and p_{sj}. Thereby, the transmission power of node s meets

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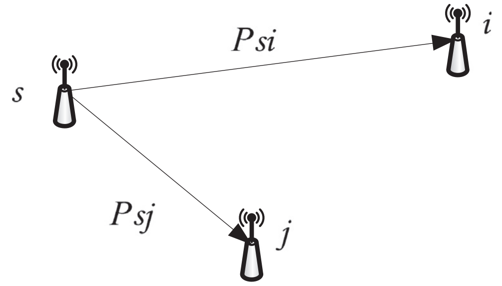


Fig. 1. The transmission model of nodes.

$$p_s(i,\ j) = \max\left\{p_{si},\ p_{sj}\right\} \tag{1}$$

If using transmission power $p_s(i,\ j)$, node s can communicate normally with nodes i and j. Additionally, each node uses omni-directional antenna transmit and receive data packets.

3.2. *Node cooperation sleeping*

In this paper, we use the amplify-and-forward to perform the cooperation of nodes. This method only amplifies and forwards the received data packet transmitted by source node Moreover, it holds the low implementation complexity. To attain the higher energy efficiency, we propose to use the sleeping mechanism to reduce network energy consumption. When not receiving or forwarding data packets, nodes stay at the sleeping status.

The example of the sleeping mechanism is introduced in a collaborative communication shown in Fig. 2, where *S* stands for the source node, *D* denotes destination node, and coop represents the cooperative node. The data packet transmission in the co-operative unit includes two stages: stage 1 and stage 2. Stage 1 is the cooperation node's receiving phase as shown in Fig. 2(a), where node *D* is in the idle stage, without receiving information. Stage 2 is shown in Fig. 2(b), where the cooperation node directly amplifies and forwards the received data packets to destination node *D*. Fig. 3 denotes the corresponding sequence diagram for Fig. 2. Thereby, through the sequence diagram, we can obtain the status information of each node in the communication process within the cooperation unit.

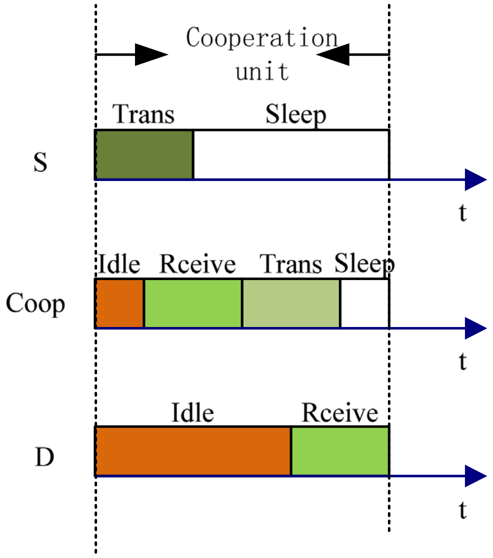


Fig. 3. The sequence diagram of cooperation communication.

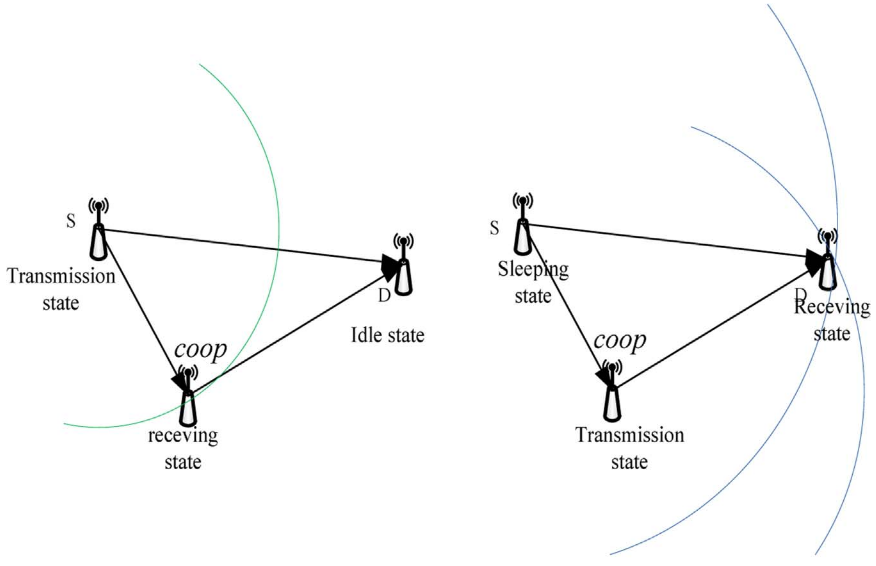
3.3. *Energy efficiency model*

In this paper, energy consumptions in the multicast communication includes those of transmitting, receiving, and sleeping. Generally, the multi-hop wireless network can be abstracted into a simple directed graph $G(B, A)$, where B is node set and $|B| = n$ and A is link set. As discussed above, it is assumed that in our network model, each node uses the omni-directional antenna to transmit and receive data packets. The link established between two nodes meets the following equation:

$$P_i \cdot \frac{1}{R_{ij}^{\alpha}} \geq SNR_j \tag{2}$$

where P_i is the transmission power of node i, R_{ij} is the distance between nodes i and j, α is the link fading index with the value between 2 and 4, SNR_j stands for SNR requirements of node j.

Next, we use the amount of information successfully delivered



(a) stage 1 (b) stage 2

Fig. 2. Schematic diagram of cooperation communication.

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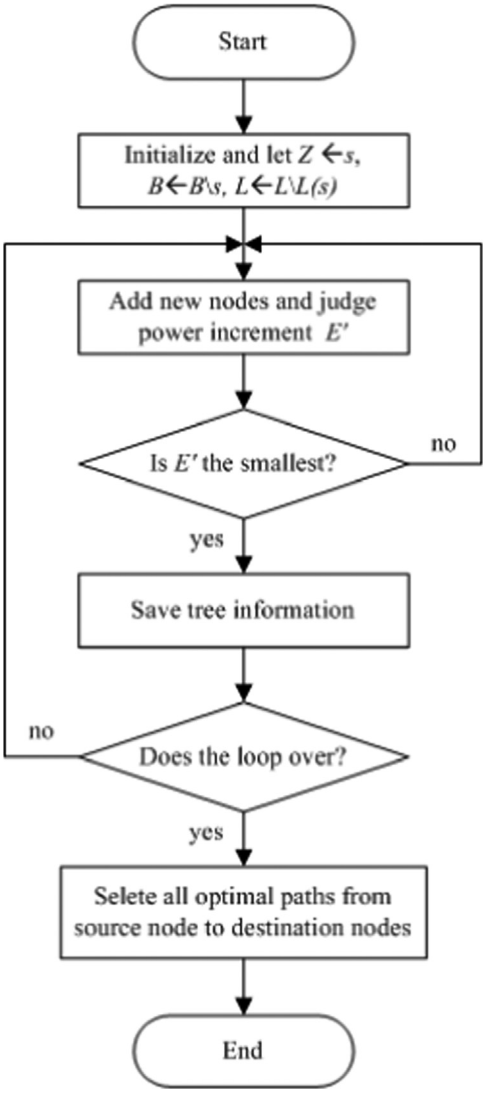

Fig. 4. The flowchart of multicast path construction.

per unit energy consumption, namely energy efficiency, to characterize network performance and energy consumption. For the multi-hop wireless network studied in this paper, network energy efficiency is denoted as

$$EE = \frac{I}{\sum_i^N E_t(i) + \sum_j^M E_r(j) + \sum_l^K E_{sleep}(l) + \sum_v^V E_{idle}(v)} \tag{3}$$

where EE represents energy efficiency with unit of bit/J, I denotes the amounts of information successfully delivered; $\sum_i^N E_t(i)$ denotes transmitting energy consumption, i stands for the transmitting node, N is the number of transmitting nodes; $\sum_j^M E_r(j)$ is receiving energy consumption, j denotes the receiving node, M is the number of receiving nodes; $\sum_l^K E_{sleep}(l)$ denotes sleeping energy consumption, l stands for the sleeping nodes, K is the number of sleeping nodes; $\sum_v^V E_{idle}(v)$ represent energy consumption when the nodes are idle, v stands for the transmission node, V is the number of idle nodes. Here each node can stay at the transmitting, receiving, sleeping, or idle status, respectively. The energy consumption of each node in each status can be obtained by the following equations:

$$E_t(i) = P_t(i) \cdot d_t(i) \tag{4}$$

$$E_r(j) = P_r(j) \cdot d_r(j) \tag{5}$$

$$E_{sleep}(l) = P_s(l) \cdot d_{sleep}(l) \tag{6}$$

$$E_{idle}(v) = P_{idle}(v) \cdot d_{idle}(v) \tag{7}$$

where $P_t(i)$ and $d_t(i)$ denote the transmitting power and transmitting duration of node i, respectively; $P_r(j)$ and $d_r(j)$ denote the receiving power and receiving duration of node j, respectively; $P_s(l)$ and $d_{sleep}(l)$ denote the sleeping power and sleeping duration of node l, respectively; $P_{idle}(v)$ and $d_{idle}(v)$ denote the idle power and idle duration of node v, respectively. Generally, there exists $P_{sleep} < < P_{idle} < P_r < P_t$.

In this paper, we are aiming at maximizing network energy efficiency in Eq. (3). Thereby, the problem to solve by this paper is how to build the most appropriate multicast paths and how to select the optimal cooperation and sleeping strategies to obtain the maximum energy efficiency for multi-hop wireless networks.

4. Energy-efficient cooperative multicast

Next, we discuss and derive our energy-efficient cooperative multicast approach.

4.1. Multicast path construction

For the given source node s and destination nodes $d = \{d_1, d_2, \ldots, d_h\}$ where h denotes the number of destination nodes in the multicast communication, we use the minimum increment energy consumption to build all the multicast path from the source node to each destination node. Based on the Multicast Incremental Power (MIP) algorithm in Ref. [44], we propose a new Minimum-energy-consumption Multicast Path Construction (MMPC) algorithm. MMPC is also helpful for applications in Refs. [45,46]. The pseudo code of MMPC algorithm is denoted in Algorithm 1 in detail.

Algorithm 1. multicast path construction.

```
1   Input node set $B$, source node $s$, and destination
2     node set $d = \{d_1, d_2, \ldots, d_h\}$
3   Output multicast path tree $R$
4   Algorithm process:
5     $T \leftarrow s$;
6     $B \leftarrow B/s$;
7     $L \leftarrow L/L(s)$;
8   While $(B \neq \varnothing)$
9      $i \leftarrow$ min power tree$(L)$;
10     $T += i$;
11     $L \leftarrow L/L(i)$;
12  End while
13  While $(d \neq \varnothing)$
14    Select path $p_i$ of source node $s$ to destination
15      node $d_i$ from multicast tree $T$;
16     $R \leftarrow p_i$;
17     $d \leftarrow d/d_i$;
18  End while
19  Output $R$
```

For Algorithm 1, lines 5–7 are the initialization process. Lines 8-12 are the loop which is used to build all possible path with minimum

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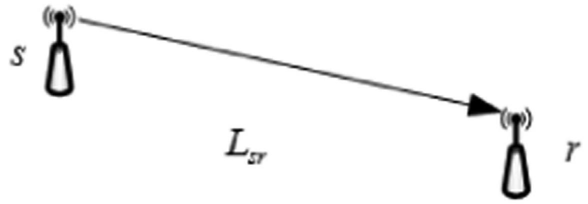
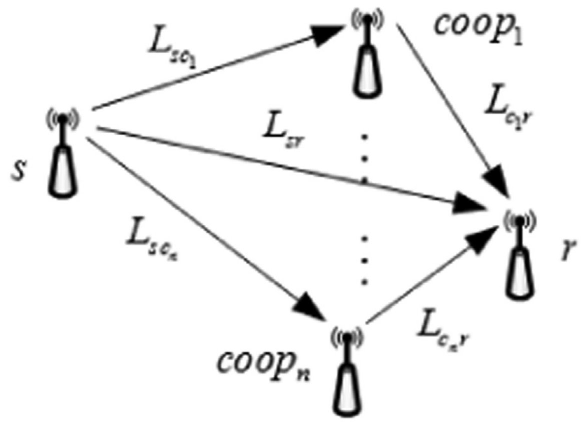


(a) Non-cooperative transmission.



(b) Cooperative transmission.

Fig. 5. Two types of transmission modes.(a) Non-cooperative transmission.(b) Cooperative transmission.

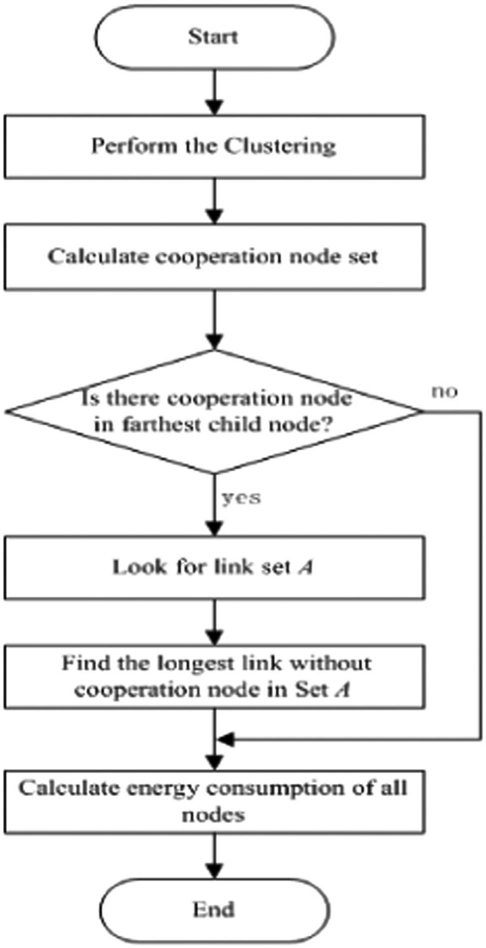


Fig. 6. The flowchart of TPM algorithm.

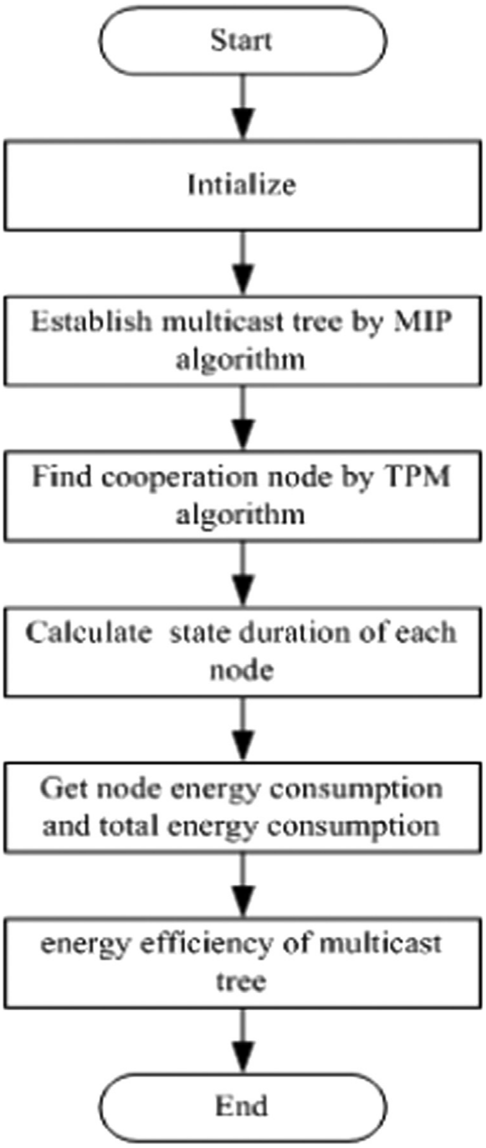


Fig. 7. The flowchart of TCEM algorithm.

energy consumption. Lines 13-18 are also the loop which is exploited to select the optimal multicast tree path. Line 19 is to output multicast tree attained. The flowchart of Algorithm 1 is plotted in Fig. 4.

4.2. Topology control-based cooperation

To perform the energy-efficient multicast communication, we further optimize the multicast tree obtained above. Without loss of generality, the transmitting power of each node is variable and it can be calculated by Eq. (1), while the receiving power, idle power, and sleeping power are regarded as the certain fixed values. In the case of meeting the SNR constraint, the receiving node can correctly receive and forward the signals sent by different transmission nodes. Thereby, we can adjust the transmitting power of each node to perform topology control and achieve the appropriate cooperation communication among different nodes. We use cooperation communication theory to improve network performance in this paper.

After introducing the cooperation of nodes, for the communication process in multi-hop wireless networks, the received signal power of nodes meets the below equation:

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$$\frac{\sum_{i=1}^{n} P_{coop_i r} + P'_{sr}}{N} \geq \varsigma \tag{8}$$

where $P_{coop_i r}$ represents the signal power received by the receiving node from the *ith* cooperation node, P'_{sr} denotes the signal power received by the receiving node from the transmitting node, N is the local thermal noise, and ς represents the SNR threshold at the receiving node. In the cooperation process, the cooperative node must be able to correctly receive the information from the transmitting node. That is, the transmitting node is to cover all the nodes to participate in the cooperation. Thereby, each transmitting node meets the following equation:

$$P'_s \frac{1}{L_{sc}^{\alpha}} > \min\left\{P_{sc_1}, P_{sc_2}, ..., P_{sc_n}\right\} \tag{9}$$

where P_{sc_i} denotes the signal power received by the *ith* cooperative node ($i = 1, 2, .., n$), L_{sc} represents the distance able to reach by the transmitting node, α is the channel fading factor, and n stands for the number of cooperative nodes.

According to the constraint in Eq. (9), the cooperation nodes perform the cooperation for the information delivery between a certain pair of nodes. Therefore, the cooperation nodes meet two conditions:

Condition 1. The cooperation nodes should be able to correctly receive the information sent by the sending node, so it is necessary to ensure that the distance between the transmission node and cooperation nodes is less than the distance between the transmission node and the receiving node:

$$L_{sc_i} < L_{sr}, \quad i = 1, 2, ..., n \tag{10}$$

where L_{sc_i} is the distance between the transmitting node and the cooperation node, L_{sr} is the distance between the transmitting and reception nodes.

Condition 2. Because the cooperation node need to forward the received data, the distance between the cooperation node and receiving nodes is also less than the distance between the sending node and the receiving node, namely:

$$L_{c_i r} < L_{sr}, \quad i = 1, 2, ..., n \tag{11}$$

where c_i, s, and r denote cooperation node i, the sending node s, and the receiving node r, respectively.

Next, to achieve the above goal, we are to use topology control to let each transmitting node exploit minimum transmission power to finish the information delivery. Without loss of generality, we analyze two transmission mode, namely direct transmission (namely non-cooperative transmission) shown in Fig. 5(a) and cooperative transmission shown in Fig. 5(b), where s and r, respectively, denote the sending and receiving nodes, $coop_i$ (where $i = 1, 2, ..., n$) represents n cooperation nodes. According to Fig. 5, we attain the below equation:

$$P_s \cdot L_{sr}^{-\alpha} = P'_s L_{sr}^{-\alpha} + \sum_{i=1}^{n} \left(P_{coop_i} L_{c_i r}^{-\alpha}\right) \tag{12}$$

where P_s denotes the minimum transmission power of node s in the direct transmission mode in Fig. 5(a), P'_s is the minimum transmission power of node s in the cooperation mode in Fig. 5(b), and P_{coop_i} is the minimum transmission power of cooperation node i. Eq. (12) indicates that, to achieve the reliable delivery, the minimum signal power received by node r in the direct transmission mode is equal to that received by node r in the cooperation transmission mode.

Eq. (12) can be converted as:

$$P_s = P'_s + \sum_{i=1}^{n} P_{coop_i} \left(\frac{L_{c_i r}}{L_{sr}}\right)^{-\alpha} \tag{13}$$

Because Eq. (11) holds and α is a constant value from 2 to 4. Then we obtain the below equation:

$$P_s > P'_s + \sum_{i=1}^{n} P_{coop_i} \tag{14}$$

Eq. (14) shows that the transmitting energy of transmission node in the cooperation mode is lower than that in the direct transmission mode. Accordingly, we get the following energy consumption equation:

$$E_t + E_r > E'_t + E'_r + E_{tc} + E_{rc} \tag{15}$$

where E_t and E_r, respectively, denote the transmitting and receiving energy consumption of all the nodes in the non-cooperative mode; E'_t and E'_r, respectively, represent the transmitting and receiving energy consumption of all non-cooperative nodes; E_{tc} and E_{rc}, respectively, stand for the transmitting and receiving energy consumption of all cooperative nodes in the cooperative mode.

Thereby, in the cooperative mode, the total energy consumption can be denoted as:

$$E_{tree} = \left(\sum_{j=1}^{n} E_{tj} + \sum_{k=1}^{q} E_{rk} + \sum_{i=1}^{m} E_{tc_i} + \sum_{z=1}^{m} E_{rc_z}\right) \tag{16}$$

where E_{tj}, E_{rk}, E_{tc_i}, and E_{rc_z}, respectively, represent nodes' transmission energy consumption, reception energy consumption, and cooperation energy consumption in the multicast tree

The flowchart and pseudo code of TPM algorithm are, respectively, shown in Fig. 6 and Algorithm 2.

Algorithm 2. The pseudo code of TPM algorithm

```
for i=1…n
   Tree ; % construct a tree by MIP;
   coop_set ← node(Lsc<Lsd&&Lcd<Lsd); %find the
                                       % cooperation nodes set;
   if (fareastset~=∅) %the fareast sonnode have cooperation node
      set_sc ← (node); %find the link set of transnode
                              % to farest cooperation;
      L>Lsc; %find link that the distance of
                  the link > transnode to farest cooperation;
      link_set = ∅; %find the link that no have cooperation node;
      E; %compute the consumption of multicast tree;
   end if
end for
E_tree; %get the average consumption of tree;
```

4.3. Energy-efficient routing algorithm

In the subsection, we propose a TCEM approach to raise energy efficiency of the multi-hop wireless network for smart medical applications, which is based on the TPM algorithm. In our algorithm, the transmission of data only occurs between two nodes. In the traditional communication mode, most of the other nodes in

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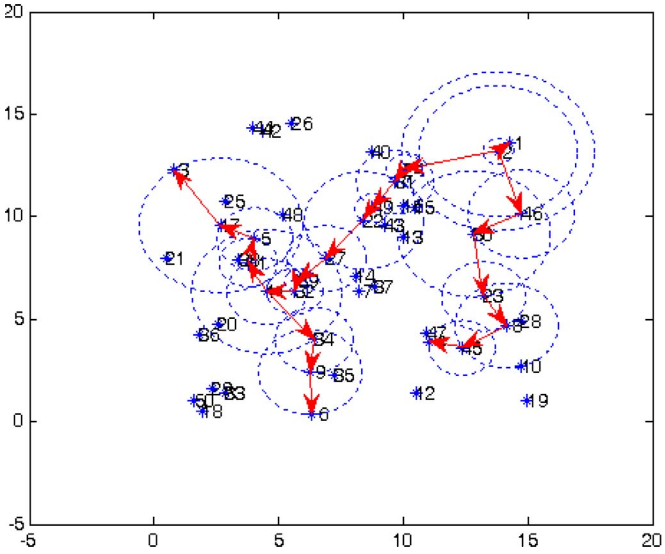

Fig. 8. The multicast tree structure for algorithm MIP.

the multicast tree are in an idle state, while these nodes still consume the energy. In order to better save network energy and improve network energy efficiency, we introduce the sleep mechanism into the multicast tree, which can effectively save the energy and improve energy efficiency. TCEM algorithm first obtains the status information of all nodes of the multicast tree in the communication period, calculates their duration in the corresponding state, and gets network' energy consumption and energy efficiency. The steps and pseudo-code of TCEM algorithm shown in Fig. 7 and Algorithm 3.

Algorithm 3. The pseudo-code of algorithm TCEM

```
for i=1...n
    tree ← [node1, node2]; %get a tree by MIP;
    coop_set ← node(Lsc<Lsd&&Lcd<Lsd);
                            %find the cooperation nodes;
    NSI ← (trans,reveive,idle,sleep);
                    %get the state of all nodes in multicast tree;
    TNS ← (T_trans,T_reveive,T_idle,T_sleep);
    %get the duration time of every state of all nodes in multicast tree;
    E_tree; %get the energy consumption of tree;
    EE_tree; %get the energy effieient of tree;
    EE;    %sum of the energy effieient;
end for
avrage_EE = EE / n; %get the avrage energy effieient;
```

4.4. A study case

In the above section, we propose three algorithms. What is following, we introduce a study case to describe the specific application of these algorithms. The steps of the study case are as follows:

Step 1: Use the MIP algorithm to establish a multicast tree as shown in Fig. 8. Start from the source node to establish an optimal multicast tree. In Fig. 8, the number of source node is 2 in our simulation and the number of destination nodes are {1,3,4,5,6}, respectively.

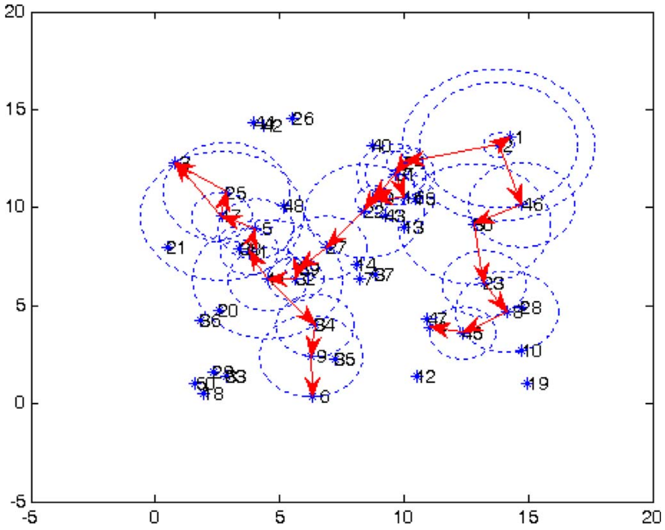

Fig. 9. The multicast tree structure for algorithm TPM.

Step 2: Find the collection of cooperation nodes that corresponding to each link in the multicast tree. In the simulation process, not all links have cooperation nodes, as shown in Fig. 9. By calculating, find that the link from 17 to 3 has a cooperation node 25 and the link from 31 to 19 has a cooperation node 16.
Step 3: The cooperative link that has been found is not always able to participate in the cooperation. This needs to determine whether there is cooperation nodes in the furthest child nodes of the link. Only in the case there has cooperation node in the furthest nodes, the cooperation node of the link can be possible to join the cooperation. After selecting, the link which is satisfied with the cooperation constraint may be deleted.
Step 4: Add the qualified cooperation node to the multicast tree. Then create a new multicast tree as shown in Fig. 9.
Step 5: Calculate the transmission power of each node. For the cooperation nodes, their transmit power is equal to the minimum power which the reception node is able to correctly receive the information.

Fig. 10 shows the timing diagram of three algorithms in the cooperation unit.

5. Simulation results and analysis

5.1. Simulation environment settings

In the performance evaluation of our method, we take different simulation conditions into account. We assume that there are N nodes in the multi-hop wireless network, which are set as 30, 40, 50, 60 and 70. All the nodes are randomly distributed in a 15 km × 15 km square region. In the simulation process, we suppose that the link fading factor α is equal to 2. The number of destination nodes is from 1 to n, where n is much smaller than N. There are at most 5 destination nodes. We assume that the received power is a constant value and the threshold of signal-to-noise ratio is set to 1. In this paper, the related variable parameters are the network size and the destination nodes with random set. During the simulation, we assume that the source node needs to send a specific number of packets and the packets size are fixed, discussing the performance of sending one data packet in average. In the following, we validate our algorithm by a series of simulations.

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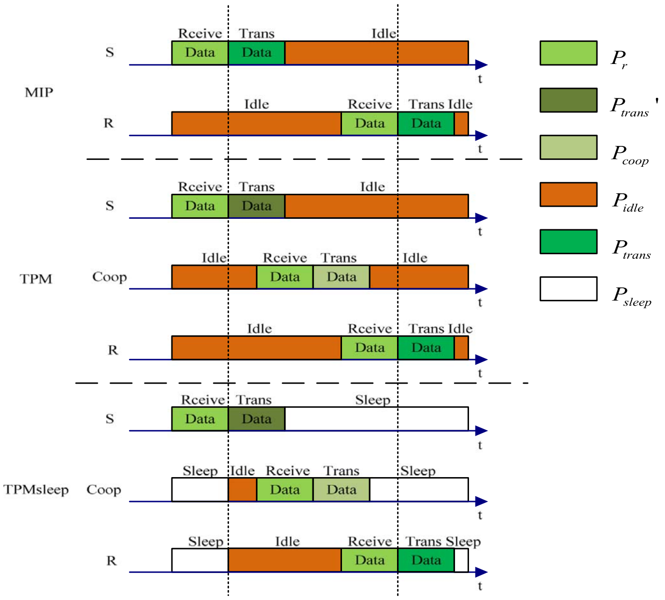

Fig. 10. The time sequential diagram of three algorithms.

5.2. Impact of network size

In this subsection, we discuss the impact of network size on the performance of our algorithm TCEM. The simulation scenario is in a 15 km × 15 km square area, where network nodes are randomly distributed, the source node number is 2, and the collection of destination nodes is {1, 3, 4, 5, 6}. To attains the accurate simulation results, we perform the 1000 runs to calculate the average value.

The simulation results are shown in Figs. 11 and 12, where the red curve is the average energy consumption and energy efficiency of networks for algorithm TCEM, respectively; the blue curve stand for the average energy consumption and energy efficiency of networks for algorithm MIP, respectively; the green curve is the average energy consumption and energy efficiency of networks for algorithm TPM. The x-axis is network scale, while the y-axis denotes the average energy consumption and energy efficiency of three algorithm. Fig. 11 shows that, in the 15 Km × 15 Km region, when the number of network nodes is increased, the average energy consumption of networks for three algorithms is decreased. This is because the density of the network nodes becomes large with the size of the network increasing. Accordingly, the distance between the nodes in the multicast tree is shorter, while the transmission power of the node becomes smaller. In such a case, the energy consumption of networks is reduced. Compared with other two algorithms, TCEM always holds the minimum network energy consumption. This shows that our algorithm can attain the better energy saving performance.

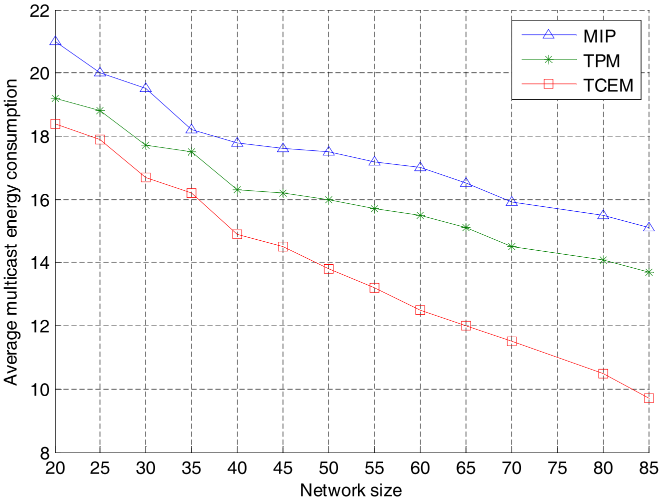

Fig. 11. Impact of network size on energy consumption of networks. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

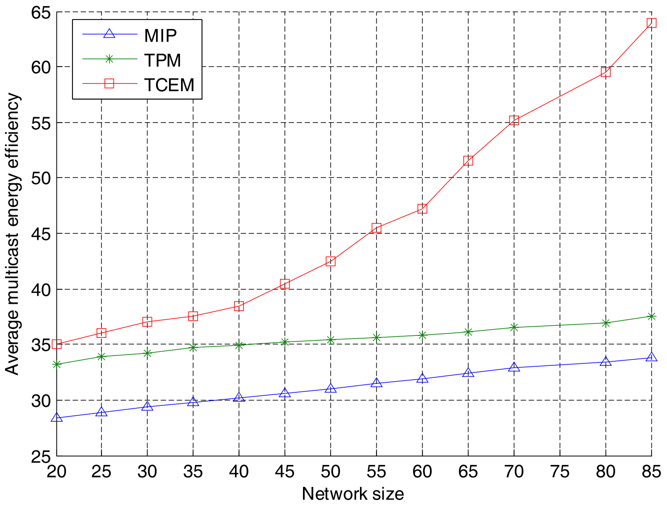

Fig. 12. Impact of network size on energy efficiency of networks. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 12 shows the impact of network size on energy efficiency of networks for three different algorithms. From Fig. 12, we can see that when the number of network nodes becomes large, the energy efficiency of networks for three algorithms is gradually becoming large. This is because for transmitting the same data packets, the lower energy consumption can be used to forward the more data packets. Thereby, we can attain the results as shown in Fig. 12. It is very interesting that Fig. 12 indicates that TCEM keeps up the largest energy efficiency of networks among three algorithms. This further demonstrates that TCEM holds the better energy efficiency performance.

5.3. Impact of the number of destination nodes

To further validate the performance of our algorithm, we analyze the impact of the number of destination nodes on the performance of three algorithms. In the *15 km* × *15 km* simulation scenario, 50 network nodes are randomly distributed. The source node is 2; the collection of the destination nodes is, respectively, {1}, {1, 3}, {1, 3, 4}, {1, 3, 4, 5}, and {1, 4, 5, 6}. For each case, we perform the 1000 runs to calculate the average value.

Fig. 13 and 14 indicate the impact of the number of destination nodes on the energy consumption and energy efficiency of networks for three algorithms, where the red curve is the average energy consumption and energy efficiency of networks for algorithm TCEM; the blue curve represents the average energy consumption and energy efficiency of networks for algorithm MIP; the green curve stands for the average energy consumption and energy efficiency of networks for algorithm TPM. The x-axis denotes the number of destination nodes; the y-axis is the average energy consumption and energy efficiency of networks for three algorithms. Fig. 13 shows that with the number of destination nodes increasing, the average energy consumption of networks for three algorithms is gradually increasing. This is because for the certain network size, the density of the nodes is invariant. In such a case, when the number of destination nodes becomes large, the number

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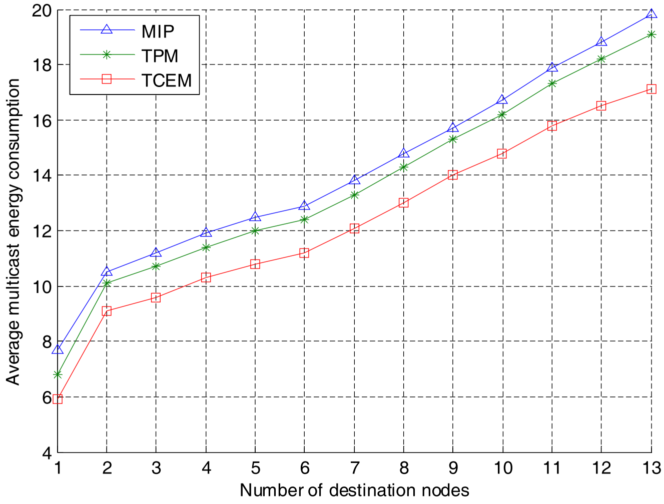

Fig. 13. Impact of the number of destination nodes on energy consumption of networks.

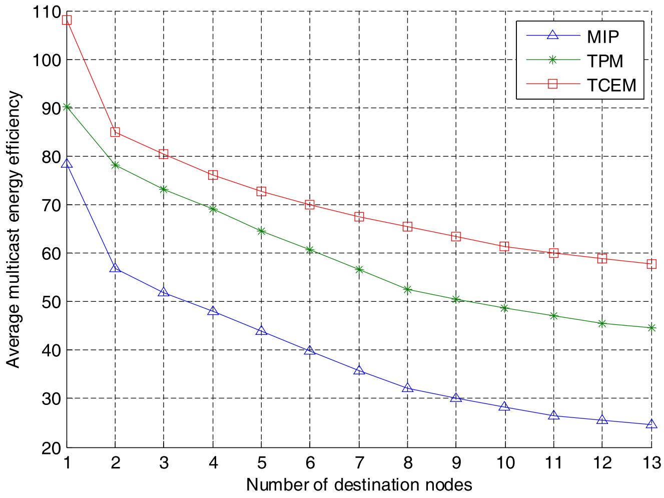

Fig. 14. Impact of the number of destination nodes on energy efficiency of networks.

of network nodes in the multicast tree increases. Therefore, the more network nodes will take part in the sending and receiving process of data packets. This leads to the larger energy consumption of networks for three algorithms. From Fig. 13, it is very clear that TCEM holds much lower energy consumption than other two algorithms. This demonstrates that TCEM can achieve network performance.

Fig. 14 shows that with the number of destination nodes increasing, the energy efficiency of networks for three algorithms is gradually decreasing. This is because for the same sent data packets, the larger energy consumption leads to the lower energy efficiency of networks. From Fig. 14, we can also find that when the destination nodes increase, the energy efficiency curve of TCEM is far over those of other tow algorithms. This shows that for different destination nodes, TCEM still exhibits the better energy efficiency performance than other two algorithms.

6. Conclusion

This paper investigates the highly energy-efficient multicast routing in multi-hop wireless networks to improve users' quality of experience for smart medical applications. With smart medical being extensively applied to individuals and hospitals, high energy consumption of communications between smart medical devices and hospitals has become a highlighting problem, particularly for the scenarios of multi-hop wireless communications with the limited energy. To this end, we proposes an energy-efficient multicast routing approach to multi-hop wireless networks for smart medical applications. Different from previous methods, we target the energy efficiency of networks as a subject function to attain the highly energy-efficient networking scheme. Accordingly, topology control and sleeping mechanism are used to obtain the optimal routing strategy with maximum network energy efficiency. The corresponding algorithms are presented to seek the energy-efficient optimal route in the multi-hop communication. Simulation results show that the proposed approach is effective and feasible.

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