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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