Enhancing Battery Lifetime of Wireless Heterogeneous and Ad hoc NW

Debashree Nayak, Saumendra Kumar Mohanty and Amiya B. Sahoo

Abstract The principal objective of next generation wireless access networks (NWs) is to provide quality of service at anywhere, anytime, and any type of environment. As the user mobile nodes (MNs) basically depend on their battery power, to provide best service, it is most important to minimize their energy consumption. Considering this factor, battery lifetime is maximized through cooperative game theory. Here, we have also applied a route selection algorithm to ad hoc MNs to get them attached with the appropriate attachment point with less power consumption. The experimental MATLAB simulation results show the cooperative act of MNs and NWs to maximize the battery lifetime, and the route selection algorithm can also balance the load among proxy MNs by which they will not be overloaded.

Keywords MANET · Cooperative game process · Battery lifetime · Ad hoc NW · Route selection

1 Introduction

In mobile ad hoc NW (MANET), the power consumption means the maximization of battery lifetime of the whole system. So, the ad hoc mobile nodes (MNs) should choose their appropriate attachment points accordingly.

In [1], we have applied cooperative game theory to maximize battery lifetime of the MNs, taking load balancing into account to avoid NW congestion. To solve the problem of NW selection, we have applied a multi-tenderee bidding model to the

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whole cellular coverage area. Other VHO decision algorithms such as SAW, TOPSIS, etc., are implemented in Ref. [2] with their standard deviations. In [3], the network selection algorithm is formulated as a cooperative bidding process, taking only the overlapping region of all the heterogeneous access networks. The idea of network selection with cooperative act of NWs is presented in Ref. [4]. In [5], a VHO decision algorithm is presented that enables a wireless access NW to not only balance the overall load among all attachment points but also maximize the collective battery lifetime of MNs. In addition, when an ad hoc mode is applied to 3G or 4G wireless data NWs, a route selection algorithm is proposed for forwarding data packets to the most appropriate attachment point to maximize collective battery lifetime and maintain load balancing. In [6], a series of experiments is described which gives detail measurements of the energy consumption of an IEEE 802.11 wireless NW interface operating in an ad hoc NW environment. In [7], minimum energy dynamic source routing (MEDSR) and hierarchical MEDSR protocols for MANET are proposed. The comprehensive analytic model is developed in [8] for the performance study of the route DSR protocol for MANET. This paper is organized as follows: In Sect. 2, a VHO scenario with ad hoc NW is introduced. In Sect. 3, the CGP is applied to enhance the battery lifetime of MNs in the heterogeneous NW and a route selection algorithm is applied to maximize the collective battery lifetime for the ad hoc NW. Section 4 shows the experimental results with discussion. In Sect. 5, conclusion and future works are provided.

2 Handoff Scenarios

NW selection is a great challenge for a heterogeneous environment in terms of its QoS, bandwidth, mobility, etc. VHO in urban areas may take place at anywhere and at anytime. Here, we have introduced a VHO scenario, taking ad hoc NW into consideration as shown in Fig. 1b. That means in addition to the vertical handoff region, as shown in Fig. 1a, if there exist some MNs that are not placed in the coverage areas of any access NWs, handoff process may take place to get connected with the nearest access NWs. In such a situation, the MNs may form a MANET and forward their data packets to the most appropriate APs or BS. In this system, the MNs act cooperatively to form a MANET using the IEEE 802.11 interface in an ad hoc mode as shown in Fig. 1b.

3 Battery Lifetime

3.1 Cooperative Game Process

Let p_{il} be the power consumption per unit of time needed in lth MN at ith NW. The value of p_{il} depends on the number of MNs attached to the ith NW and the data rate requested by lth MN, that is, larger the number of nodes attached to the same

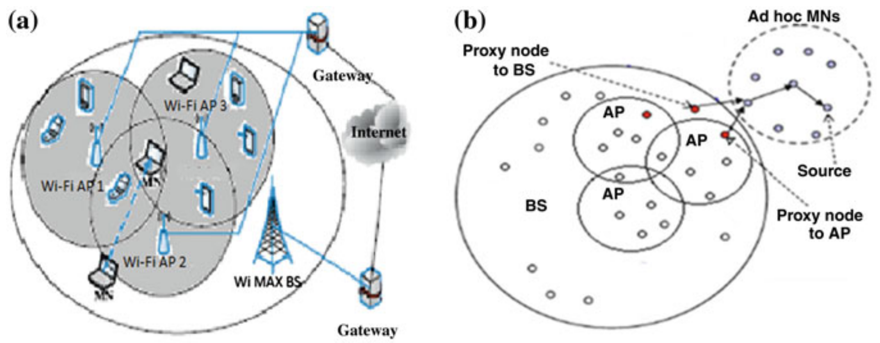

Fig. 1 **a** Handoff scenario of heterogenous NW. **b** Handoff scenario of ad hoc NW

AP, the more power consumed by each MN, as they each get lower data rates and hence need to connect longer [5]. Thus, the amount power consumed by MNs is as follows:

$$p_{il} \propto R_i \tag{1}$$

where R_i is the utility of ith NW and is given as

$$R_i = \frac{U\_B_i}{T\_B_i} \tag{2}$$

where U_B_i: Used bandwidth of ith NW and T_B_i: Total bandwidth of ith NW.

To maximize their battery lifetime, the MNs calculate their load on each NW to avoid NW congestion. If the load on a particular NW is higher than a threshold value, the MNs under that NW will be affected. So, the MN having largest battery power in that NW will go for the NW having second lowest power consumption rate for it. In this process, the game will be played in rounds till the load on each NW is balanced.

3.2 Route Selection Algorithm

For the NW of Fig. 1b, when an MN is actively receiving the data frames from a BS or AP of a cellular NW, experiences a low downlink channel rate and the VHDC cannot find an alternative direct access point for the MN, a route will be selected via the MANET to allow the MN to access an appropriate attachment point of its choice. The source MN in ad hoc NW sends out a route request message using its IEEE 802.11 interface which is broadcasted through the ad hoc NW to all the MNs according to the route discovery protocol [5]. The objective is to find an optimal relay route in terms of overall battery lifetime, to reach a MN (proxy node) with a high downlink channel rate to an attachment point. Simultaneously, the selected attachment point updates its routing table entry while sending a relay acknowledgement message to the proxy node. When the proxy MN receives the data frames from its corresponding NW, it forwards the frames to the next relay node. The route selection algorithm [5] balances the battery lifetime of the ad hoc MNs which relay traffic for other MNs in ad hoc NW. In heterogeneous wireless NW without ad hoc support, the battery lifetime of each MN is considered to be related to the load at its attachment point. But in a heterogeneous wireless NW with ad hoc support, the amount of traffic that each MN relays has a great impact on the battery lifetime of the MN. Hence, all the MNs in the NW must participate in relaying each other's data frames. Thus, this algorithm considers the amount of traffic load to be forwarded and maximizes the battery lifetime of the MNs in the available routes, which results in maximizing the overall battery lifetime of the system.

Let J be the amount of traffic that has to be routed via some MNs in the cellular coverage area and p_{kb} be the power consumption amount per byte of transmission at a given MN k. Then, the cost function is defined as

$$E_k = \frac{p_k}{p_{kb}J} \tag{3}$$

The maximum battery lifetime resulting from the selection of a given route r_s is determined by the minimum value of E_k over the path, i.e.,

$$L_s = \mathrm{Min}_{\forall k \in r_s} E_k \tag{4}$$

Let A be the set of all possible routes between kth MN that is experiencing a low downlink channel rate and candidate attachment points via proxy MNs in the ad hoc NW. Here, the attachment point has been already selected by the NW selection algorithm (bidding model and cooperative game process), with which the candidate proxy node is associated. Then, the route $r_{\max}$ with maximum battery lifetime value from the set A is selected as follows:

$$r_{\max} : \ \mathrm{Max}_{\forall r_s \in A} L_s = \mathrm{Max}_{\forall r_s \in R}(\mathrm{Min}_{\forall k \in r_s} E_k) \tag{5}$$

4 Experimental Results

Simulation Parameters:

Number of MNs in the VHO region: 22
Number of traffic classes: 4 (best effort, background, video, and VoIP)
Number of candidate NWs: 4 (AP-1, AP-2, AP-3, and WIMAX BS)
Number of parameters: 5 (bandwidth, delay, jitter, packet error rate, and price)

After the final round of bidding process, the MNs will act cooperatively to maximize their battery lifetime. From Fig. 2, the battery lifetime of 12 MNs is

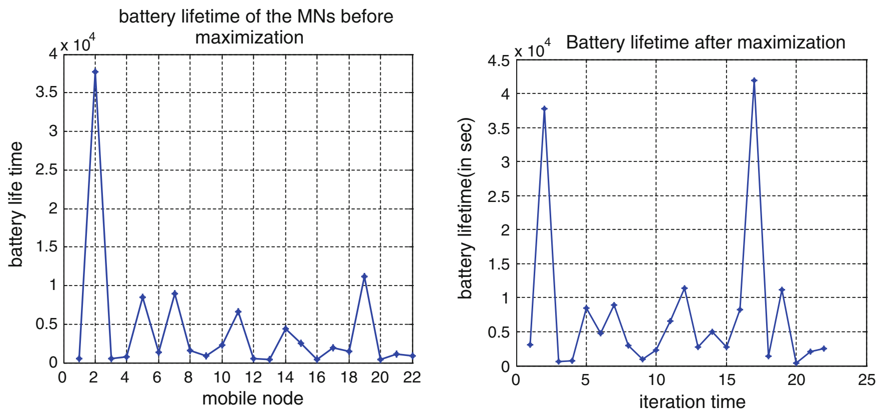

Fig. 2 Battery lifetime of each NW in the bidding process before and after maximization

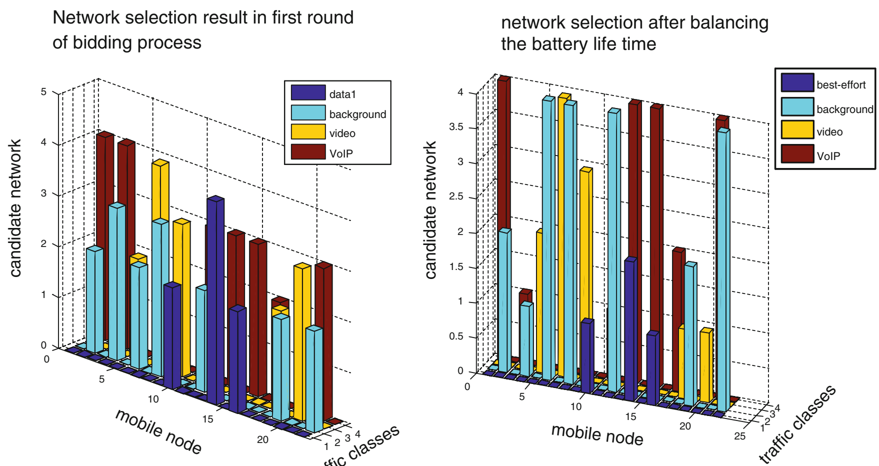

Fig. 3 Final NW selection result before and after maximization of the battery lifetime

increased by the CGP and the 10 MNs have same battery lifetime as before, that is, they will get the maximum battery lifetime in that NW, whose bid is the lowest one for them.

Figure 3 shows the final NW selection results after maximization where the NW utility of the four access NWs are 0.9649, 0.9604, 0.9617, and 0.9687, respectively.

By applying the route selection algorithm, the MNs in ad hoc NW select the attachment points which are shown in the above Fig. 4. In our experiment, the MN having maximum battery lifetime in each NW is acting as the proxy MN. So, the power consumption in the four proxy MNs (0.8 + 2.4 mj/kB × J) are 39.6226, 32.5013, 42.4925, and 45.6066, respectively. From the route selection algorithm described above, the ad hoc MNs have selected their attachment point, where they

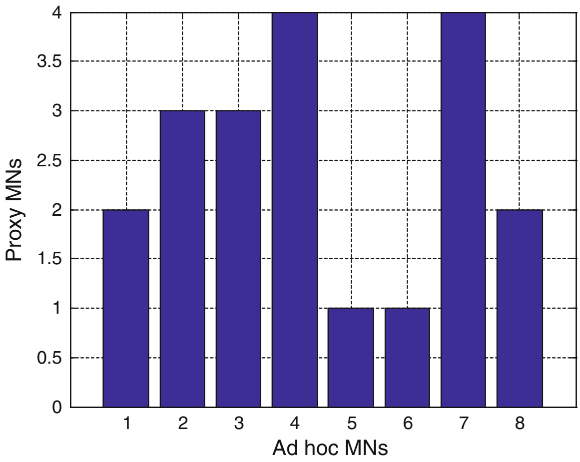

Fig. 4 Selection of appropriate attachment points through proxy MNs by the ad hoc MNs

can stay connected longer and at the same time, the load is evenly distributed among the 4 proxy MNs so that each have consumed about equal energy.

5 Conclusion and Future Work

In our work, we have applied cooperative game theory to maximize the battery lifetime of the MNs in heterogeneous access NWs and for the other MNs which are not present in the cellular coverage area, a route selection algorithm is applied to connect them with their appropriate attachment points. From this work, we have concluded that through the route selection algorithm, an MN present outside of the cellular coverage area (i.e., ad hoc NW) can be connected to its appropriate attachment point and by the battery lifetime maximization process, it can stay connected longer with the attachment point. The standard deviation of this VHO decision algorithm is obtained as 0.0032, whereas the standard deviation of some other algorithms such as SAW and TOPSIS are 0.0137 and 0.0117, respectively.

As the cooperative game process has successfully applied to maximize the battery lifetime of the MNs in cellular coverage area, it can also be applied to the multi-hop ad hoc NW. Apart from the MANET, the route selection algorithm can also be applied to vehicular ad hoc NW.

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