Acta Technica 62 (2017), No. 5A, 33–44

Wireless mesh network multicast routing based on power distribution

Jian Xiao[1]

Abstract. The paper aims to establish the maximum number of service users that should be accepted with no interruption and to establish the multicast routing network framework, which is used to maintain the time to reach the target maximal total profits when the entire wireless mesh network has limited energy and different device powers in each network node. The profit-oriented multicast algorithm proposed in this paper adopts cross-layer to design the dynamic distributed channels and to maximize the balanced profit between the power consumption and improvement of the service to users. Subsequently, the efficiency of the entire multicast routing network can be improved.

Key words. Battery-based wireless mesh network, multicast routing, power distribution, channel distribution.

1. Introduction

The rapid development of wireless networks and establishment of related hardware environments promoted the development of wireless mesh network (WMN) technology (I. F. Akyildiz,et al,2005). WMNs can attract attention and obtain popularity in remote areas. Compared with traditional wired networks, WMNs are not restricted by the limited wire lengths. Moreover, WMNs have many advantages, such as a large coverage area, easy constructability, higher extension, and self-organization. Hence, WMN has a potential to become a mainstream in the future.

At present, the wireless technology of WMNs is extended based on IEEE 802.11, offering various services such as video conference, multimedia audio, real-time video transmission, and the currently popular cloud technology. All of these services are within the application range of WMNs. WMNs can transmit information through the mesh router during the communication process. The MR used as the port of the gateway facilitates the communication with other wireless network system frameworks. Each MR device should be installed with a wireless base station (AP,

[1]Workshop 1 - Hunan International Business Vocational College,Changsha, 410200,China

access point) for providing wireless network service and forming the entire WMN framework.

Interruption problems among the frequencies when WMNs transmit data packets can influence the quality of network communication. The general distributed channel method uses the 802.11 b/g as an example. Targeting the three available orthogonal channels, many studies have mainly discussed how to do a more effective channel configuration to enable more users to obtain channel resources without interruption under the limited resource. The CLACA proposed in reference (Wen-Lin Yang,et al,2013) can dynamically distribute the channels whose links have no interruption in each node. The number of users in the entire network after being distributed is superior to that of the other algorithms. In other words, the quality of wireless transmission is provided to more users without interruption. Therefore, this paper establishes a multicast tree based on the algorithm. The node in the tree represents the device providing the ad hoc wireless network, and the concept of load value is added during the process of establishing the multicast tree. It also means that the number of users served at the device nodes of the entire network framework. The clients assigned in each of the nodes are different so that the actual state of the wireless network can be simulated.

Meanwhile, some references reported that the power in each node device can be stably provided without limitation during the process of discussing the mesh network. Therefore, concern over the consumption of power of the nodes at any time is unnecessary. Each node has its own power supply, which can supply limited power to complement the energy of device outdoor or in remote areas or hills, but the possibility of stopping the communication transmission of the network with the unstable supply of power or the limited (in terms of time) power supply should be considered. Furthermore, it cannot continue to serve the users at a certain point. If one of the nodes in the device is not functioning, the other connected devices will be affected, paralyzing the operation of the entire network. Therefore, the maintenance time of the entire wireless mesh network must depend on the volume of power in the individual nodes of the device. Meanwhile, the operation time of the entire network is also limited to the node whose device energy is the minimum with the restriction of the power so that the establishment of the entire wireless mesh network can not only serve the users but also consider the entire power consumption.

The above descriptions show that the energy consumption of the entire wireless network should be minimized so that the longest time can be maintained in the premise of supplying limited energy to the network. Theoretically, serving more users and maintaining the duration in the entire network is expected. The device energy is limited and the users in each device node are different in the actual situation. The more device the network has, the larger the power consumption during the transmission. In this way, the entire network cannot be operated for a long time. If the number of nodes is less, the maintaining time of the entire network can be improved. The served users can be influenced for the less number of the node devices so that the requirements in the real life cannot be met. Therefore, obtaining a balance between the served users and the improvement of the maintaining time in the entire network are discussed in this paper. In addition, maintaining a high transmission quality without interruption, serving the maximal number of the clients, and maintaining the longest network serving time are discussed in this paper.

This paper also introduces three other kinds of algorithms used for establishing the multicast tree. The targets pursued by these algorithms are different. Efficiency analysis can be applied to compare these algorithms, and the proposed algorithm is based on the power consumption and distribution of the uninterrupted channels in the experiments.

2. Directed prim multicast tree

The directed prim multicast tree (DPMT) algorithm judges whether an antenna is directional or omni-directional according to the size of the antenna angle θ $(0 \leq \theta \leq 360)$. The transmitted energy Pvu[3] from node v to the node u can be defined as follows:

$$P_{vu} = \frac{\theta_v}{360} r_{vu} \tag{1}$$

where r_{vu} is the distance between the two nodes, α is the power of the distance, and its range is $2 \leq \alpha \leq 4$. It shows that the power consumption and the θ_v angle have a positive relationship. The RB-BIP method or the RB-MIP method was discussed in the reference (Jeffrey E,et al,2002). An omni-directional antenna first establishes BIP or MIP and obtains the positions of each node. Subsequently, the minimum angle of the directional antenna, which covers these nodes, can be calculated, and the weighted value should be calculated by checking the link between the node inside the tree and the most neighboring outside the tree. The weighted value equals the power consumption of the two connecting nodes and the power volume of the nodes outside the tree. Then, the node whose weighted value is minimum should be selected to add in the multicast tree.

2.1. MIP Tree

The operating time of the entire network depends on the time power consumed in the individual nodes because the volume of the battery in each node of a device in WMNs is different. In addition, the power consumed during transmission has a positive relationship with the distance, and the transmitted distances are different; thus, the total transmitted time should be maintained by reducing the power consumed in the entire network using the algorithm.

According to reference (Jeffrey E, et al, 2002), BIP algorithm is similar to Prim algorithm. If the MIP tree needs to be obtained, the BIP tree should first be established. The BIP tree should adopt the features of the wireless broadcast advantage. It regards the source as the original point in the node cluster and then checks which node is in the tree or is not added in the tree. Then, the consumed P'_{ij}during the process of adding the $link\,(i,j)$ should be calculated, as shown in the following formula:

$$P'_{ij} = P_{ij} - P(i) \tag{2}$$

where P_{ij} represents the energy required by $link(i,j)$ itself, $P(i)$ is the energy lever consumed by node $i$in the transmission state, and $P(i) = 0$is the leaf node of the tree in node i. If P'_{ij} is less than or equal to 0, other energy should not be consumed by adding the node j and then the node which consumes the minimum P'_{ij}should be selected to be added in the tree until all nodes have been added in the broadcast tree. After the broadcast tree is established by BIP, the MIP tree can obtain the multicast tree by reducing the nodes or branches in the tree in terms of the requests.

2.2. MCM + Best-First Tree

The distribution of uninterrupted channels should also be considered during the process of establishing the multicast tree. It assumes that a total power column can control the power consumption of the entire network to a certain value. The distributed channel method can complete the multi-channel multicast tree after the establishment of the tree under the limited energy condition of the entire network. Generally, the transmitted data can cause interruption with the neighboring or joint-linked and limited channel resources (G. Zeng, et al, 2007). The lesser the number of relay nodes, the higher the need to avoid interruption. Therefore, the MCM tree can adopt the node number needed from the minimum relay node and source node to the target node to establish the multicast tree.

After the MCM tree is established, best-first (WL. Yang, et al, 2012; M. Peng, et al, 2007) is adopted to distribute the channels. First, after the root node of the tree is set as the father node, whether the channels can be shared by linking with the neighboring link of the father nodes should be checked. If it cannot be shared, whether the remaining available channels can cause interruption with the neighboring or jointly connected channels should be checked next (Kolipaka Sujatha, et al, 2014). Then, each sub node is in turn regarded as the father node to repeat the above steps to form a MCM tree, which has distributed the channels, after each link distributes the channels and removes the connected nodes that were not distributed(Egners Andr?,et al,2013; Choi S,et al,2016).

2.3. Definition

This paper aims to search for the basis of establishing the algorithm whose efficiency is the optimal in the entire wireless mesh network with a custom efficiency function (Oe K,et al,2015; Zhao X,et al,2015). The following assumptions should be satisfied. 1. The maximum profit in the entire WMNs multicast tree should be obtained while considering whether the serving users can be improved or the entire consumed power can be reduced. 2. Each device should consider its position, especially in areas where power cannot be stabilized with the limited battery volume and the different power volumes of the device nodes, simulating the actual situation. 3. The established multicast tree network should serve the number of clients, which have a certain ratio, to avoid the situation of non-compliance with the actual condition of having less network servers.

According to the above conditions, the total profit function is proposed to estimate the efficiency of the entire WMNs, as shown in the following formula:

$$Total\,profit \;=\; Serviced\,clients * Life\,time \tag{3}$$

The definition implies the efficiency appraisal of the entire network. The size of the values can be decided by multiplying the serviced clients and the Life time. The higher the value is, the higher the total profit of the network. The serviced clients should be larger than or equal to a certain ratio of the clients. Otherwise, its combination can serve few users for a longer time and cannot comply with the actual profits even if the value of the total profit is high. The served users should be above 10% of the total number of users in the paper to maintain the service quality of the entire network, and the duration time of the network should be maximal as soon as possible. This means that it can serve the time of the entire users simultaneously. Therefore, the paper emphasizes how to obtain the balance between serviced clients and life time so that the maximal profit can be obtained by checking all algorithms through the total profit standard and the limitation of users under the uninterrupted environment.

2.4. Profit-oriented multicast algorithm

The profit-oriented multicast proposed in this paper can obtain the weighted value according to the battery volume, the load value, and the consumed energy in the joint link Then, the new multicast tree can be established by coordinating the cross-layer channel distribution for obtaining the maximal total profit. Figure 1 illustrates the algorithm, and Figure 2 shows the details of the algorithm. According to the above procedure and the algorithm, the divided steps can be shown as follows:

1. The randomly configured undirected graph should be changed into a directed graph and the breadth first search algorithm should be adopted to endow a lever value and a random power that is larger than 0 in each node. Then, surplus links should be deleted and its direction is decided by comparing the sizes of the two level values in the individual links of the entire graph. A signal-directed link should be selected to establish a directed network framework.

2. Call the load computation function, as shown in Figure 3. The node at the bottom of the max level should be endowed with the load value, and the correct load value of each node should be calculated by accumulating the load value with the use of the level method from high to low.

3. The weighted value should be calculated from the links found in step (1), and the weighted values of the individual links are as follows:

$$load(u) * \frac{\varepsilon(u)}{power dissipation of link(u,v)} \tag{4}$$

where load(u) represents the load of the node, $\varepsilon(u)$represents the power of node

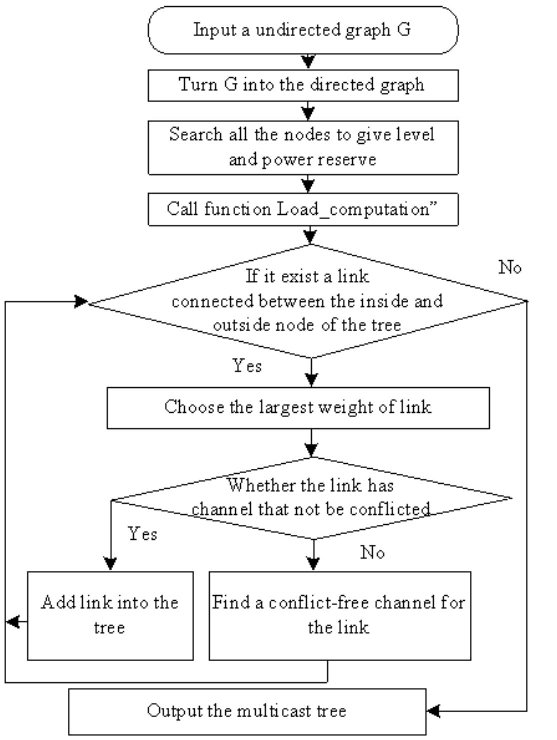

Fig. 1. Procedure of the POM algorithm

u, and gateway node s should be added in the new multicast tree T.

4. Check all users, which should be larger than 0 and not belong to the node of T. The defined collection L is the link between all inside nodes and outside nodes of T. All links within collection L should be compared, and the link whose weighted value is the maximum should be determined.

5. When the link can accept the channels shared with node u, its link should be added into T. Otherwise, an uninterrupted channel should be assigned to it, as shown in Figure 3

6. If the uninterrupted channels cannot be determined to distribute the links, the link should be deleted. Then, other links within collection L should be continued until all links have been checked. Otherwise, step (9) can be directly performed.

7. The users of the nodes in the old and new multicast trees should be set to 0, and the load of all nodes in the old multicast tree and the linked weighted values should be recalculated.

8. Steps(4) to (7) should be repeated until collection L becomes the black collection.

9. The new multicast tree T should be the output, and then the entire algorithm procedure can be ended.

```
Input: Given an undirected graph G = (V, E) representing the mesh
network, the gateway node s, destination set M = {u|u ∈ V, req(u) > 0},
and energy reserve Ɛ(u) ∀u ∈ V.
1. Convert G into a directed graph G′ = (V, A) by making each undirected
edge in E become two opposite directed links.
2. Starting from the gateway s, assign each node a level value based on the
BFS traversal. Delete the backward link.
3. l = (u, v), where level(u) > level(v), l ∈ A;
4. Call load_computation(G′) to find load(u), ∀u ∈ V;
5. For each link l = (u, v) ∈ A, compute weight(u, v)=
```

$$load(u) * \frac{\varepsilon(u)}{power\ dissipation\ of\ link(u,v)}$$

```
6. Let T = (V¯, E¯), V¯ = {s}, Z = V − V¯, E¯ = ∅;
7. While (M ⊄ V¯) {
8. Let ℒ = {(u, v)|u ∈ V¯, v ∈ Z};
9. Choose a link l ∈ ℒ, where weight(l) ≥ weight(k), k ∈ ℒ;
10. If (link l can share the channel λ that has been allocated to u) {
11. Add l into T;}
12. Else {
13. Find a conflict-free channel λ for l;
14. If (λ ≠ null) { Add l into T;}
15. Else {
16. Delete l from ℒ;
17. If (ℒ ≠ ∅), go to step 9; Else break "while" loop;} }
18. For (u ∈ M and u ∈ V¯){req(u) = 0;}
19. Call load_computation(G′) to re-compute load(u), ∀u ∈ V;
20. For each link (u, v) ∈ A, compute weight(u, v);
}
21. Output channel-allocated multicast tree T;
```

Fig. 2. POM algorithm

```
Load_computation (G) {
1. Let max Level = max level(u) u   V;
2. Let load(u)   demand(u), for each leaf-node
u   V;
3. For (l = maxLevel; l   0; l   l   1) {
4. For (each node u with level(u) = l ) {
5. If (node v is adjacent to node u ){
6. If ( level(v) < level(u) )
{ load(v)   load(v)   load(u) ; }
7. Else, if ((level(v) == level(u))
{ load(v)   load(v)   demand(u) ;}
8. }}}
```

Fig. 3. Function load computation

3. Experimental experiments

The experiment was about the Total Profit as the standard of the algorithm efficiency, and it multiplies the served users and the time of the fastest power con-

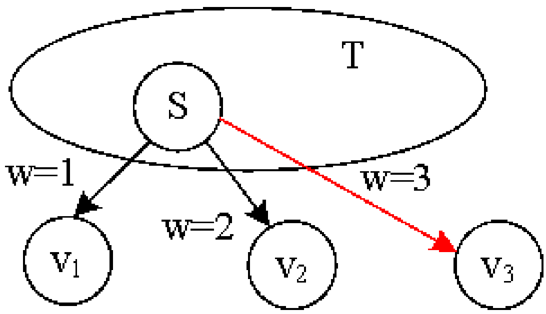

Fig. 4. Select the maximum link of the weighted value w

sumption in the nodes. The experiment adopts the Java and Quaint platforms to simulate the actual situation and estimate the efficiency of each algorithm.

1. The Java procedure is adopted to simulate the real situation of multicast tree and obtain the load value and the time of the fastest power consumption in the nodes. Then, the total profit can be obtained. Total profit = Load * Time.

2. The Qualnet 5.0.2 software is adopted to simulate the consumed time when the battery is used up. Formula (3) is obtained by multiplying the consumed time and the load value.

The experiment adopts three other algorithms as control groups and compares them with the POM algorithm proposed in the paper.

The Java experimental simulations first assume that five different users are required in the node of the entire multicast tree. The load value can be obtained by recording different terminal numbers in each tree using the Java procedure. The consumption time of power in each link can be obtained by dividing the power of each node in the tree by the joint links of the nodes. In this manner, the shortest time should be regarded as the shortest operating time of the network. Then, efficiency can be obtained by multiplying the two factors above. In the same experimental conditions, the POM algorithm proposed in the paper can obtain the maximal total profit under the uninterrupted environment simultaneously, as shown in Figure 5.

The Quaint experimental simulations show that five types of the archives (App, Member, Node, Display, and Config) can be obtained with the use of the Java procedure output after each algorithm stipulates the initial simulated conditions. Subsequently, it is used as input and should be simulated by the Quaint simulation. The information on the obtained static archive should be analyzed and the algorithm should be verified through the actual values. The obtained data belonging to the information of the 20 multicast trees in each algorithm should be averaged.

Table 1. Initial condition of the experiment

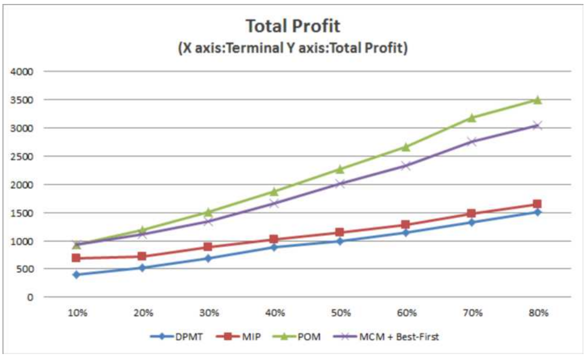

Fig. 5. Results of the total profit obtained from the Java-simulated experiment. The total profit obtained from the POM algorithm (the green line) in each terminal situation is superior to that from other algorithms.

Simulated parameters	Values
Total number of the nodes	100 nodes
Node rate of the multicast tree	10%–80%
Initial power of the device	10–20 mAhr
Simulated time	3600 s
Number of transmitted packets	200
Size of the packets	512 bytes

Compared with the throughputs of the established multicast tree in each algorithm, it represents the size of the received packet total data in the entire multicast tree. When the total transmitted packets are fixed, the higher the value is and the more target nodes connect to the multicast tree. The results obtained from the POM algorithm introduced in the paper are superior to those from other control groups, as shown in Figure 6.

The Throughputs obtained from the POM algorithm (the green line) in each terminal situation are superior to those from other algorithms.

The battery model established in Quaint can set the initial battery volume in the individual device in advance and simulate the power consumption of the device or the surplus of the battery. The experiment adopts JAVA to distribute the battery volume in each device node for outputting the multicast tree in each algorithm. After the wireless network transmission is simulated by the Quaint, which operated for an hour, the time data can be obtained when the power consumption in each device is 0. Then, Formula (3) can be obtained by multiplying the load value, as shown in Figure 7. The experimental data obtained from the two platforms show that the efficiency in the POM is higher than that in other common algorithms.

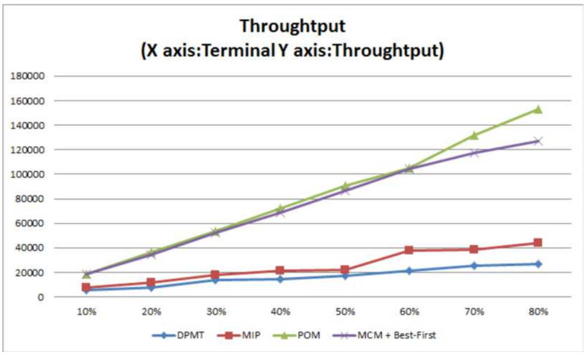

Fig. 6. Throughputs are obtained from the Quaint experiment

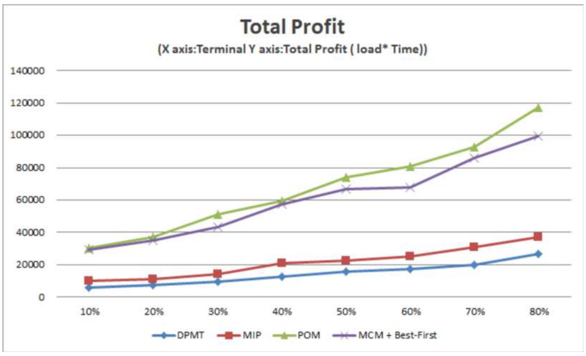

Fig. 7. Total profit obtained from Qualnet

4. Conclusion

The paper extends the research on power consumption based on the cross-layer adjusting channel distribution. Through the actual experiment data in Java and Quaint and the standards proposed in the paper, the total profit obtained from multiplying the load value and the network maintaining time proves that the efficiency in the proposed method is better than that in other algorithms. Therefore, the proposed POM algorithm is suitable for establishing the served users and maintaining an uninterrupted multicast tree implementation for a long time based on power consumption.

References

[1] F. Akyildiz, X. Wang, W. Wang: *Wireless mesh networks: a survey.* Computer Networks (2005), No. 47, 445–487.

[2] W. L. Yang, W. T. Hong: *A cross optimization for maximum multicast in multi-channel multiradio wireless mesh networks.* International Journal of Communication Systems *27* (2013), No. 11, 1–19.

[3] E. Jeffrey. W. selthier, D. Gam, N. guyen: *Energy-Aware Wireless Networking*

with Directional Antennas: The Case of Session-Based Broadcasting and Multicasting. IEEE Transactions On Mobile Computing *1* (2002), No. 3, 176–191.

[4] E. Jefferey. W. selthier, D. Gam, N. guyen: *Energy-Efficient Broadcast and Multicast Trees in Wireless Network.* Mobile Network and Applications *7* (2002), No. 6, 481–492.

[5] G. Zeng, B. Wang, Y. Ding, L. Xiao, M. Mutka: *Multicast Algorithms for Multi-Channel Wireless Mesh Networks.* IEEE ICNP *21* (2007), No. 1, 1–10.

[6] W. L. Yang, W. T. Hong: *Channel allocation strategies for interference-free multicast in multi-channel multi-radio wireless mesh networks.* Ksii Transactions on Internet & Information Systems *6* (2012) 629–648.

[7] M. Peng, Y. Wang, W. Wang: *Cross-layer design for tree-type routing and level-based centralized scheduling in IEEE 802.16 based wireless mesh networks.* IET Communications *1* (2007), No. 5, 999–1006.

[8] K. Sujatha, B. N. Bhandari: *Performance analysis of AODV with multi-radio in hybrid wireless mesh network.* IFIP International Conference on Wireless and Optical Communications Networks *11* (2014), 1–5.

[9] E. Andr, H. Patrick, J. Tobias: *Experiences from security research using a Wireless Mesh Network testbed.* Proceedings - Conference on Local Computer Networks (2013), 340–343.

[10] S. Choi, J. H. Park: *Minimum Interference Channel Assignment Algorithm for Multicast in a Wireless Mesh Network.* Sensors *15*, (2016), No. 12, 20–56.

[11] Y. Kumar: *Proposal and Performance Evaluation of a Multicast Routing Protocol for Wireless Mesh Networks Based on Network Load.* Mobile Information Systems (2015), 1–10.

[12] X. Zhao, J. Guo, C. T. Chou: *High-Throughput Reliable Multicast in Multi-Hop Wireless Mesh Networks.* IEEE Transactions on Mobile Computing *14* (2015), No. 4, 728–741.

Received November 16, 2017