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OPTIMUM POWER MANAGEMENT IN MOBILE AD-HOC NETWORKS

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Abstract

Mobile Ad hoc Network is an interconnection of mobile nodes, with no fixed infrastructure. Optimum management of power is very important in MANET as all its nodes are battery operated. If a node fails to forward the data packets from other nodes and just utilize the network to send its own data, the network will definitely face connectivity issues. The nodes which behave in such a selfish manner are termed as selfish nodes. Many research works have found ways for eliminating the selfish nodes. But elimination of nodes will reduce the connectivity and lifetime of the network. In this paper instead of eliminating, the selfish nodes we have tried to eliminate the selfish behaviour by maintaining the sanctity of every node involved in the MANET formation. This will help in improving the connectivity and lifetime by reducing selfish behaviour in individual nodes.

Keywords: Battery power, Mobile ad-hoc network, Network lifetime, Optimum power management, Selfish node.

1. Introduction

As the entire world is shifting towards wireless mode, a lot of research is going on to provide various connectivity options. One of the options is the Mobile Ad hoc Network (MANET), where we can establish the connection between various nodes without any fixed infrastructure. Here the lack of centralized point of contact is compensated by the routing and forwarding operation performed by every node in the network. So every node plays an important role in the well-being of the network.

The nodes participating in the ad hoc network can be classified as benevolent

Nomenclatures

B	Total battery capacity, J
Bd	Instantaneous battery charge dissipated, J
Br	Battery power remaining, J
Br %	Battery power remaining in percentage, J
Bs	Battery charge spent at a particular instant, J
D	Battery dissipation, j
Di	Battery dissipation during idle time, J
Dp	Battery dissipation during transmission of one packet, J
I	Idle time, s
L	Battery total lifetime, s
P	Number of packets
Pt	Number of packets transmitted
T	Total time, s
Tp	Transmission time for one packet, s

Abbreviations

AODV	Ad-hoc on-Demand Distance Vector
BP - AODV	Battery Power based Ad-hoc on-Demand Distance Vector
CP - AODV	Credit Point based Ad-hoc on-Demand Distance Vector
DSDV	Destination Sequence Distance Vector
DSR	Dynamic Source Routing
H. P	High Priority
LAR	Location-Aided Routing
L. P	Low Priority
MANET	Mobile Ad Hoc NETwork
M. P	Medium Priority
N. P	No Priority
RERRs	Route Errors
RREPs	Route Replies
RRP	Reactive Routing Protocol

or malevolent, based on their behaviour. Benevolent nodes are perfectly cooperative and they keep the network going by forwarding other node's packets. Malevolent nodes are not cooperative and in times, they try to disrupt the entire network. These malevolent nodes are further classified as selfish and malicious nodes. Selfish nodes take part in the network activities only for forwarding its own packet. In other words, it uses the network selfishly and refuses to help other nodes. However, malicious nodes try to steal other nodes data, they imitate other nodes, they also tell lies about their neighbour's availability, they send unwanted data into the network, and these are few of the disrupting activities of malicious nodes. Here in this paper, we focus on overcoming the issues caused by the selfish nodes. This selfish behaviour of a node may be due to the urge to save scarce battery power, bandwidth, computational capacity and connectivity. Among the various reasons, the tendency to save battery power is the single most reason for many nodes behaving selfishly.

As the network density scales, the connectivity increases and with that the burden of monitoring the nodes behaviour and the data overhead associated with it also increases. If we have few nodes the monitoring load and overhead are less, but we can have only lesser connectivity. So there is always a trade-off between the effective monitoring and available bandwidth. The two main classifications of MANET routing protocol are the reactive and proactive approach. The reactive approach reduces overhead, by calculating the route only when there is a necessity. Whereas in the proactive protocol the route to all possible destination nodes are constantly calculated and updated, which will result in increased overhead. Therefore, by keeping in mind the need for effective utilization of bandwidth, we have selected the reactive routing protocol approach for our research work.

2. Related Work

Various research works have been carried out in order to optimize the performance of MANET. Many works have focused on the selfish node problem, as the network connectivity will be greatly affected by the selfish nodes [1-3]. This is found to be effective in identifying selfish nodes, but even when a node drops a packet once for whatever reasons, it will be booked as a selfish node and eliminated from the network [1]. Such elimination will gradually reduce the number of active nodes participating, leading to weakening of the network as well as the network lifetime.

There is a need to find the reasons for the nodes dropping packets and then classify whether its behaviour is selfish or self-protective. Samian et al. [2] tried to quantify the degree of selfishness by considering, the load of the node and also by comparing the service done by the node under study to various other nodes. In most of the work published, if a node stops forwarding packets from neighbours to save its battery power, the node will be termed selfish irrespective of the good work done previously, by the particular node in forwarding operations, until such time as it has very less battery power.

As nodes at the centre of the network will face many forwarding operations, chances are high for those nodes to lose its battery power earlier than those nodes at the periphery. Such nodes can be given an opportunity to declare that it is running out of battery and needs to recharge [3]. The other nodes can give the particular node, rest for a fixed time before routing packets through that node. In the case of energy efficient routing schemes [4], in place of the normal minimum hop routing, two different approaches are used. One is the route with least transmission energy and the second is that the route having the maximum energy nodes is selected.

Arvind et al. [5] minimized transmission energy by first searching for a path or a link to the destination within a transmission radius of 125 m and increasing it to 250 m only when the network cannot find any suitable path within the 125 m radius. The packets are routed through the path that consumes minimum transmission power and thereby the network lifetime is prolonged. In [6] a power efficient routing model was proposed where the cost function associated with a particular node for routing increases with the decrease in the battery capacity of individual nodes. Thereby the routing model discourages other nodes from sending packets through those nodes that are having less battery power.

Mishra and Sonker [7] selected multiple paths, the path having the nodes with least battery power is neglected, and from the remaining paths, the optimum path based on the requirement is selected. In the work of Anuja et al. [8], the path consisting of maximum lifetime nodes is opted for transmission, so that the overall network lifetime is increased. While Asma [9], repetitive paths are avoided to make sure energy is not drained out for a specific node alone; instead, paths are selected alternatively so that energy consumption is done in a balanced way. In Das et al. work [10], the routing is done through energy efficient paths, calculated using a fuzzy based logic. This approach will help in an overall increase of the network lifetime. In Sahnoun et al. research [11], an energy efficient proactive routing scheme in the presence of selfish nodes is proposed based on the game theoretical approach.

3. Ad-Hoc on-Demand Distance Vector (AODV) Routing

Reactive Routing Protocol (RRP) is a bandwidth-efficient protocol for MANETs. In this protocol, the source node initiates the route search process, whenever it needs to send data packets to a destination node. Thus, the need for a route triggers the process of the route search, hence the name Reactive Routing Protocol. Reactive protocols tend to decrease the control traffic messages overhead at the cost of increased latency in discovering new routes. Few examples of reactive routing protocols are Ad hoc On-Demand Distance Vector (AODV) Routing, Dynamic Source Routing (DSR) and Location-Aided Routing (LAR).

Ad hoc On-Demand Distance Vector (AODV) Routing uses a modified version of the broadcast route discovery mechanism of Dynamic Source Routing (DSR) algorithm. AODV dynamically establishes route table entries at intermediate nodes. This helps in reducing the large overhead incurred by other routing protocols in carrying source routes in each data packet. To maintain the most recent routing information between nodes AODV utilizes the concept of Destination Sequence Distance Vector (DSDV) Routing. However, AODV uses a sequence number counter, which helps it in overcoming the stale route problems. Thus by combining these two techniques, AODV minimizes the network control and data traffic [12]. Thereby AODV saves battery power as well as bandwidth and that is the reason for us to choose AODV as the base for our research work.

Route Requests (RREQs), Route Replies (RREPs), and Route Errors (RERRs) are the message types defined by AODV. AODV utilizes Route Request (RREQ) and Route Reply (RREP) messages for route discovery. Routes with the shortest hop count are preferred. Route requests with the same broadcast ID will be processed, only if it has a higher sequence number. AODV utilizes Route Error (RERR) message to handle link breakages and alert the source node about the link disconnection [13]. Nodes monitor the link status of next hops in active routes. If AODV detects a route error, it triggers a RERR, so that every node that receives the RERR message removes the corresponding entry from its routing table and rebroadcasts it. The possible causes of route error are node failure, malicious nodes, selfish nodes, packet collisions or interference.

4. Battery Power Based AODV (BP-AODV) Routing

Maximum network connectivity can be achieved only when the majority of the nodes are in active mode, but based on the working principle of routing protocols few nodes become inactive very early due to reduced battery power. As in many protocols, in AODV the focus is on the shortest path or in the least traffic path, the nodes, which often come along the most used path, will get worst, affected in terms of battery power. So to avoid this and to improve the connectivity we follow a method where in addition to the rules set for the AODV routing protocol used, we add another condition based on battery power left.

In our method, we have modified the well-established and proven reactive routing protocol called the Ad hoc on demand Distance Vector routing (AODV). In AODV in addition to the underlying protocol that takes the Distance calculation for routing, we first classify the nodes based on the remaining power left in them and set priorities for those nodes. The priority of a node is defined here as the opportunity we give for other nodes to utilize it for their data forwarding operations. We divide the power level into four categories and the nodes having power level between 0 and 10 percent is not given any priority and is excluded from the network. The Least Priority (L.P) is given for those nodes with battery power 11 to 40 percent, the nodes having power between 41 and 70 percent is given the medium priority and finally, the highest priority is set for the nodes with power level, 71 to 100 percent. The priority status is mentioned in the following Table 1.

Table 1. Battery power based distance vector routing.

Battery power	Priority status
0 to 10%	No Priority (N.P)
11 to 40%	Least Priority (L.P)
41 to 70%	Medium Priority (M.P)
71 to 100%	High Priority (H.P)

Based on this Battery power based AODV routing system whenever a need for establishing a new route arises, the source node will search for a node in the priority order H.P, M.P and then L.P. If the priority status of a node is N.P it will be totally avoided in the route establishment process. We have to follow three rules in bringing the priority into effect. The first rule is that the nodes will be allowed to transmit its own packet even if it is in the medium or least priority zone, but packets can be routed through those nodes only if we do not have any other higher priority nodes. The second rule is that if we have two paths and if in both the paths, we have nodes with the same lower priority condition, then, in that case, the shortest path will be selected. The last and the third rule is that, if we have more than 1 node with lower priority, then the path with less number of lower priority nodes will be selected for routing. These three are the rules based on which the battery power based AODV routing is built.

5. Credit Point Based AODV (CP-AODV) Routing

In Credit Point based AODV routing, the classification of flag status is based on the credit points as shown in Table 2. Initially, all nodes participating in an Ad-hoc network will be given credit points of 60. Whenever a node transfers its data packet to a destination, its credit points will be reduced by a count equal to the total number of hop counts needed to reach the destination. During the data transfer process, each node that helped in forwarding the data will be getting one credit points.

Table 2. Credit points based classification.

Credit points	Flag status	Flag
1 to 10	Red Flag	F= -1
11 to 40	Yellow flag	F= 0
41 to 100	Green flag	F= 1

If a particular node is having credit points in the range of 41 to 100, then the flag will be set to 1 and *F*= 1 is called the Green flag. All nodes having green flag will be given the highest priority while selecting the route for data transfer. If the credit range is 11 to 40, then the node will be given a yellow flag i.e. *F*= 0. This node will be given medium priority. If the range is 1 to 10, then that node will be termed a selfish node and that node will be given a red flag i.e. *F*= -1. Any node with a red flag will not be allowed to participate in the network.

6. Analytical Analysis of Battery Power Based AODV Routing

For our analytical analysis, we have taken a mobile ad hoc network consisting of 10 nodes. In this network, the analysis is done by making all the nodes to communicate to all other nodes in a round-robin fashion. Initially, the routing table was created based on the AODV protocol without applying battery power based AODV routing.

The detailed routing pathway data for the transmissions between nodes in a round-robin fashion is given in Fig. A-1 in *Appendix A*. This pathway is calculated based on the shortest path metric calculations as in AODV. In the figure, the first row shows the destination nodes and similarly, the first column shows the source nodes. The transmission from the node 1 to node 1 is considered to be the first transmission and the transmission from node 10 to node 10 is considered to be the 100th transmission. As the transmission proceeds from node 1 to all other nodes and then from node two to all other nodes and so on until the 10th node, the battery of each node decreases. The calculations were done using an analytical approach.

The distance between a node and another node is assumed to be in meters and as we are doing the routing based on the basic distance vector routing by finding the shortest path we have related the cost and the distance in a proportional manner. If the distance is one meter then the cost is equal to one. Thus, the cost and the distance values are directly proportional to each other. Table 3 gives the list of nodes to which a source node can transmit its packets with a single hop or directly.

The routing table is built based on the transmission range table given in Table 3. From the way, the cost metric is given based on the distance; we can say that all nodes are having uniform transmission power. We did not go into further details about the transmission capacity regarding whether it is unidirectional or Omnidirectional. Regarding the range of coverage the Fig. 1, showing the cost metrics between all the 10 nodes is the base for all our calculations.

The few notations of our analytical approach are: Battery charge spent at a particular instant is *Bs*, Total Battery capacity is *B*, Transmission time for one packet is *Tp*, Battery dissipation in joules is *D*, Battery dissipation during transmission of one packet is *Dp*, Battery dissipation during idle time is *Di*, Total time is *T*, Idle time is *I*, Battery total lifetime is *L*, Instantaneous battery charge remaining percentage is *Br%*, Instantaneous battery charge remaining is *Br*, Instantaneous battery charge dissipated is *Bd*, Number of packets is P and the number of packets transmitted is Pt. The bit rate of a mobile ad hoc network is said to be 2 Mbps. So the ad hoc network is capable of sending 20, 97, 152 bits in one second. Here the size of one packet is considered as one bit. Based on that the ad hoc network takes 48*ns* approximately to send one packet and for our calculations, the transmission time is considered to be one unit, which is equal to 48*ns* The equation for finding the battery charge spent at a particular instant is given as,

$$Bs = (Tp)(Pt)(Dp) + (I)(Di) \quad (1)$$

Once we know the battery charge spent we can find the remaining charge,

$$Br = B - Bs \quad (2)$$

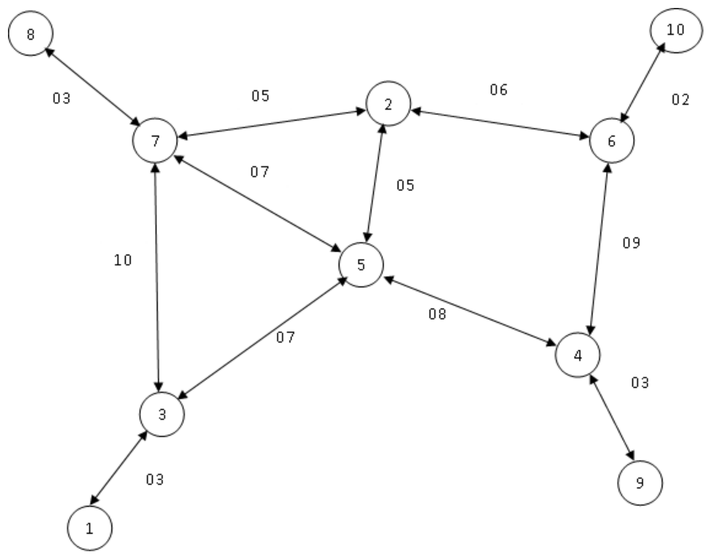

Fig. 1. MANET with 10 nodes and the cost/weight between them.

Table 3. Transmission range table.

Source node	**Destination nodes within range**
1	1, 3
2	2,5,6,7
3	1,3,5,7
4	4,5,6,9
5	2,3,4,5,7
6	2,4,6,10
7	2,3,5,7,8
8	7,8
9	4,9
10	6,10

In our calculation, we are not taking into account the battery dissipation during idle time and we only focus on the charge spent during the transmission. Figure 2 shows the battery status of each and every node during the transmissions.

From the Fig. 2 we can see how gradually the battery power of the nodes is being reduced for every transmission. Based on the assumptions we have taken for our analytical equations the power becomes directly proportional to the transmission distance i.e. the cost. Therefore, if the cost between two nodes is two then the power reduced is also two and similarly if the cost between nodes is four, then the power reduced is also four. Therefore the simplified representation is that, the battery power reduced from a node for a transmission is equal to the cost involved in that particular transmission. The last transmission we can do with all the nodes having permissible battery capacity is, transmission-79 (8, 9). With the last transmission between source node 8 and the destination node 9, the battery capacity of node 5 becomes 20 joules, which is less than the permissible amount of 25 joules. In our experiment, we will continue the transmission only until all the nodes have the battery capacity within the permissible level. Therefore, the network dies as early as the 79th transmission.

This same analytical experiment is repeated with the routing based on the battery power based AODV. In this revised routing table shown in Fig. A-2 (*Appendix A*) with the cost and route after applying the battery power based AODV routing, we can see that the transmission route is similar to the original routing table in the earlier stages of the transmission, until the priority conditions come into effect. The changes are taking effect only on the 42nd transmission, even though the batteries of node 2, 3 and 5 have gone into medium priority power limit. This is because of the rules we have in applying the priority into effect. As we know that the routing is done based on the battery power, we can understand the logic more clearly by viewing the battery status of the nodes.

In Fig. 2, we can see that again the worst affected node in terms of battery power is the node 5, which is at the centre of the networking operations. The main purpose of modifying the existing AODV protocol into BP-AODV is to help those nodes at the centre, save its battery resources so that it can prolong its lifetime. By comparing both Figs. 2 and 3, we can clearly say that the number of transmissions has increased from 79 to 104 and thereby the network lifetime has increased by a huge margin. Going by our analytical calculation, we have 31.6 percent increase in the total number of network transmissions and a directly proportional increase in the network lifetime. Moreover, we can observe that after applying the BP-AODV the reduction of battery power occurs evenly among the nodes. This further means the load sharing in terms of power is even among the nodes, which is the key factor that boosts network lifetime.

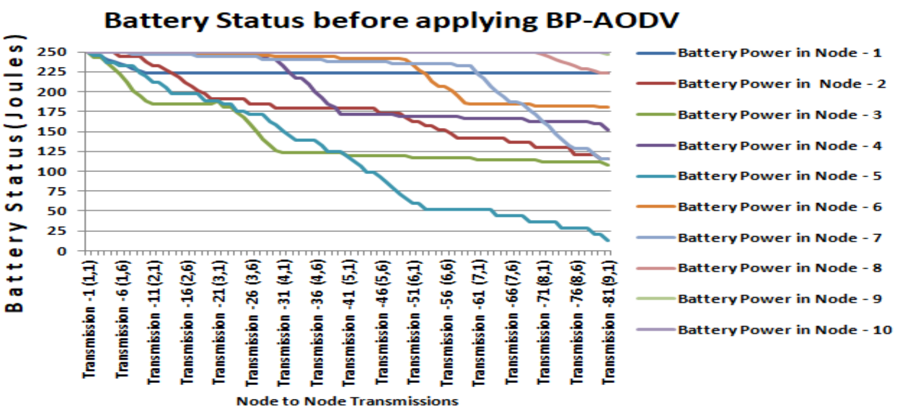

Fig. 2. Battery power status of the nodes (before applying BP-AODV).

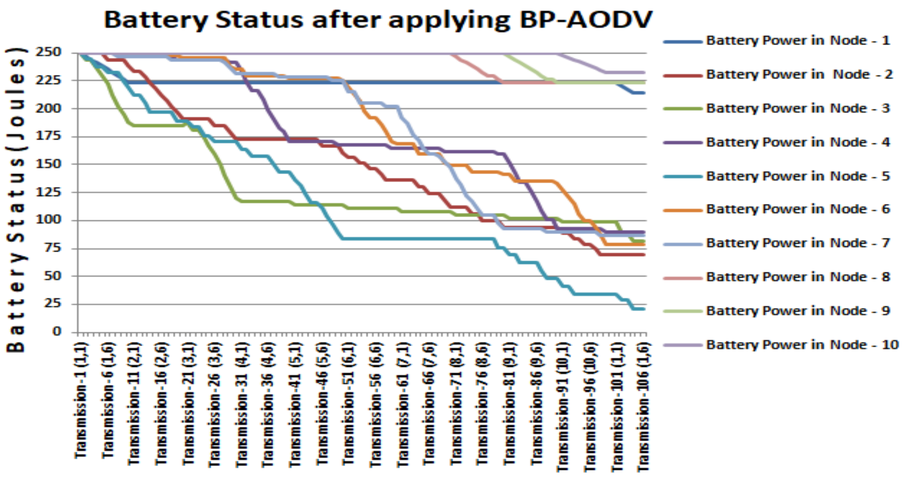

Fig. 3. Battery power remaining in the nodes from 1 to 10 after each and every transmission, after applying the BP-AODV.

We are having the maximum battery capacity of 250 Joules and the minimum battery capacity less than which a node will not be able to take part in the network activity is taken as 26 Joules. This can be observed from the Table 4 shown below.

Table 4. Battery power based AODV with priority status.

Battery power remaining in percentage (*Br %*)	Battery power remaining in joules (*Br*)	Priority status
0 to 10%	0 to 25 joules	No Priority (N.P)
11 to 40%	26 to 100 joules	Least Priority (L.P)
41 to 70%	101 to 175 joules	Medium Priority (M.P)
71 to 100%	176 to 250 joules	High Priority (H.P)

7. Conclusions and Future Work

Going by the analytical analysis of battery power based AODV routing the network lifetime can be greatly increased by properly managing the energy resources of all the nodes participating in the network. A special care and attention should always be given to those nodes that form the crux of the network, thereby getting involved in a higher number of transmissions. This can be achieved by classifying the nodes based on battery power and assigning priorities to them based on that. Thereby the number of transmissions and from that the network lifetime can be greatly increased as can be seen in our analysis we have a 31.6% increase. Thus, BP-AODV is best suited for those MANET applications where preservation of battery power and network lifetime is the priority. This work can be further continued by providing an analysis of the Credit Point based AODV (CP-AODV) routing, where credits are assigned based on the behaviour of individual nodes. We can also create a monitoring system of nodes, where nodes do the monitoring along with routing. This will ensure the effective implementation of the overall system.

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Appendix A

Data based on which the battery power chart is drawn.

Routing data after ten transmissions using AODV (before applying the Battery Power based AODV)

Source / Destination	1	2	3	4	5	6	7	8	9	10
1	1-1	1-3-5-2	1-3	1-3-5-4	1-3-5	1-3-5-2-6	1-3-7	1-3-7-8	1-3-5-4-9	1-3-5-2-6-10
	0	15	3	18	10	21	13	16	21	23
2	2-5-3-1	2-2	2-5-3	2-5-4	2-5	2-6	2-7	2-7-8	2-5-4-9	2-6-10
	15	0	12	13	5	6	5	8	16	8
3	3-1	3-5-2	3-3	3-5-4	3-5	3-5-2-6	3-7	3-7-8	3-5-4-9	3-5-2-6-10
	3	12	0	15	7	18	10	13	18	20
4	4-5-3-1	4-5-2	4-5-3	4-4	4-5	4-6	4-5-7	4-5-7-8	4-9	4-6-10
	18	13	15	0	8	9	15	18	3	11
5	5-3-1	5-2	5-3	5-4	5-5	5-2-6	5-7	5-7-8	5-4-9	5-2-6-10
	10	5	7	8	0	11	7	10	11	13
6	6-2-5-3-1	6-2	6-2-5-3	6-4	6-2-5	6-6	6-2-7	6-2-7-8	6-4-9	6-10
	21	6	18	9	11	0	11	14	12	2
7	7-3-1	7-2	7-3	7-5-4	7-5	7-2-6	7-7	7-8	7-5-4-9	7-2-6-10
	13	5	10	15	7	11	0	3	18	13
8	8-7-3-1	8-7-2	8-7-3	8-7-5-4	8-7-5	8-7-2-6	8-7	8-8	8-7-5-4-9	-
	16	8	13	18	10	14	3	0	21	-
9	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-

Fig. A-1. Routing data showing 79 transmissions using AODV routing.

Routing data after applying the Battery Power based AODV

Source / Destination	1	2	3	4	5	6	7	8	9	10
1	1-1	1-3-5-2	1-3	1-3-5-4	1-3-5	1-3-5-2-6	1-3-7	1-3-7-8	1-3-5-4-9	1-3-5-2-6-10
	0	15	3	18	10	21	13	16	21	23
2	2-5-3-1	2-2	2-5-3	2-5-4	2-5	2-6	2-7	2-7-8	2-5-4-9	2-6-10
	15	0	12	13	5	6	5	8	16	8
3	3-1	3-5-2	3-3	3-5-4	3-5	3-5-2-6	3-7	3-7-8	3-7-2-6-4-9	3-7-2-6-10
	3	12	0	15	7	18	10	13	33	23
4	4-5-3-1	4-6-2	4-5-3	4-4	4-5	4-6	4-5-7	4-5-7-8	4-9	4-6-10
	18	15	15	0	8	9	15	18	3	11
5	5-3-1	5-2	5-3	5-4	5-5	5-2-6	5-7	5-7-8	5-4-9	5-2-6-10
	10	5	7	8	0	11	7	10	11	13
6	6-2-7-3-1	6-2	6-2-7-3	6-4	6-2-5	6-6	6-2-7	6-2-7-8	6-4-9	6-10
	24	6	21	9	11	0	11	14	12	2
7	7-3-1	7-2	7-3	7-2-6-4	7-5	7-2-6	7-7	7-8	7-2-6-4-9	7-2-6-10
	13	5	10	20	7	11	0	3	23	13
8	8-7-3-1	8-7-2	8-7-3	8-7-2-6-4	8-7-5	8-7-2-6	8-7	8-8	8-7-5-4-9	8-7-2-6-10
	16	8	13	23	10	14	3	0	21	16
9	9-4-5-3-1	9-4-6-2	9-4-5-3	9-4	9-4-5	9-4-6	9-4-5-7	9-4-5-7-8	9-9	9-4-6-10
	21	18	18	3	11	12	18	21	0	14
10	10-6-2-5-3-1	10-6-2	10-6-2-5-3	10-6-4	10-6-2-5	10-6	10-6-2-7	10-6-2-7-8	10-6-4-9	10-10
	23	8	20	11	13	2	13	16	13	0
11	1-1	1-3-5-2	1-3	1-3-5-4						
	0	15	3	18						

Fig. A-2. Revised routing table using BP-AODV.