CHAPTER – III

POWER CONTROLLED AD HOC ON-DEMAND DISTANCE VECTOR PROTOCOL

3.1 INTRODUCTION

Wireless ad hoc networks are self-organizing networks without the use of any existing network infrastructure or centralized administration, which can be useful in a variety of applications including one-off meeting networks, disaster, military applications, and the entertainment industry and so on. Each node in ad hoc networks performs the dual task of being a possible source or destination of some packets while at the same time acting as a router for other packet relay. Traditional routing protocols can not be applied to ad hoc networks directly because ad hoc networks inherently have some special characteristics and unavoidable limitations such as dynamic topologies, bandwidth-constrained, variable capacity links, and energy-constrained operations compared with traditional networks. Consequently, research on routing protocols in ad hoc networks becomes a fundamental and challenging task.

The existing popular routing protocols in ad hoc networks such as Dynamic Source Routing (DSR), Destination Sequenced Distance Vector (DSDV) and Ad hoc On demand Distance Vector (AODV) are all the shortest paths, that is, the minimum hop count routings. Although these algorithms are easy to be implemented, they do not consider the
network energy consumption. The minimum hop count routings could not guarantee that the packet reaches the destination node using minimum energy consumption. Designing an effective power control strategy to reduce network energy consumption is very important and useful in some application environments such as battlefield, where node battery recharging is usually impossible. The power control in ad hoc networks determines the quality of physical layer link, MAC layer bandwidth and degree of spatial reuse, while at the same time affects the network layer routing, transport layer congestion control and QOS of the application layer. In recent years, research on routing protocols based on the power control in ad hoc networks has received increasing attention. Power aware routing schemes try to find routes which consist of links consuming low energy or prolong the network.

3.2 EXISTING SYSTEM

Existing popular routings in ad hoc network are DSR, DSDV and AODV. All these algorithms are the shortest path and minimum hop count routing doesn’t guarantee that the packet reaches the destination with minimum energy consumption. Many researchers have been done in energy reduction routing for ad hoc network but all are considered Network layer only. The goal of power control is to determine which power a transmitter should use when transmitting a packet. The optimal transmitted power of a packet depends on a large number of parameters, such as the distance from the destination, the
background noise, the amount of interference incurred by concurrent transmissions, etc.

In an ad-hoc network, the optimal power also depends on transmitting powers of other concurrently scheduled links. Since power control is tightly coupled with scheduling, it is typically implemented within the MAC protocol. Several power adaptation protocols have been proposed for power minimization scenarios. A typical example is given where the power of a link is adjusted to a minimum necessary to reach a destination, and the routing is chosen to minimize the overall power dissipation. Existing Power Routing protocols[10] are represented as follows.

**Low Power Routing Protocols**

The main focus of research on routing protocols in MANETs has been the network performance. There have been a handful of studies on power-aware routing protocols for MANETs. Presented below is a review of some of them.

**Minimum Power Routing**

This proposes a routing algorithm based on minimizing the amount of power (or energy per bit) required to get a packet from source to destination. More precisely, the problem is stated as:

\[
\text{Min}_{\Pi} \{\sum_{i,j \in \Pi} T_{ij}\}
\]  

(1)
where $T_{ij}$ denotes the power expended for transmitting and receiving between two consecutive nodes $i$ and $j$ (a.k.a. cost of link $(i,j)$) in route $\pi$.

This link cost can be defined for two cases:

- When the transmit power is fixed.
- When the transmit power is varied dynamically as a function of the distance between the transmitter and intended receiver.

Each node chooses the transmission power level for a link so that the signal reaches the receiver node with the same constant received power. To achieve this, clearly, links with larger distances require a higher transmission power than links with smaller distances. In the first case all the nodes in the network use a fixed power for all transmissions, which is independent of the link distance.

Since the power cost of transmitting and receiving is fixed, then the link cost is fixed and consequent equation (1) results in selecting a path with a minimum number of hops. In fact, assuming lossless links, a path with the minimum number of hops has a minimum number of transmissions and when the transmit power is fixed, then that path will also result in the least total power dissipation. In general, for a network with 802.11b as Media Access Control (MAC) layer, energy consumption of each operation (receive, transmit, broadcast, discard, etc.) of a packet is given by:

$$E(packet) = b \times \text{packet\_size} + c$$  \hspace{1cm} (2)
Where $b$ and $c$ are the appropriate coefficients for each operation. Coefficient $b$ denotes the packet size-dependent energy consumption that depends on distance, wireless channel conditions and so on, whereas $c$ is a fixed cost that accounts for acquiring the channel and for MAC layer control negotiation. The link cost is the sum of all the costs incurred by the source and destination nodes. Traffic is classified as broadcast and unicast (i.e., point-to-point). For unicast traffic, when receivers are in non-promiscuous mode operation, the energy cost of the link between sender and receiver may be calculated as follows:

$$T_{SD} = E_{S_{Send\ (Unicast\ Packet)}} + E_{D_{Recv\ (Unicast\ Packet)}}$$

(3)

Where $S$ and $D$ denote the sender and the destination of the unicast packet. In 802.11b, before sending a unicast packet, the source broadcasts a Request-To-Send (RTS) control message, specifying a destination and data packet size (duration of the transmission). The destination responds with a Clear-To-Send (CTS) message. If the source does not receive the CTS, it may retransmit the RTS message. Upon receiving the CTS, the source sends the DATA and awaits an acknowledgement (ACK) from the receiver. For unicast traffic with nonpromiscuous mode operations the energy cost for all non-destination nodes that can hear the packets is nearly zero since non-destination nodes only consume energy to receive the RTS packet. After this step, they will be discarded packets or even turning off their receivers during the ongoing transaction.
For unicast traffic when receivers are in promiscuous mode operation, the link cost between the sender and destination pair may be calculated as follows:

\[ T_{SD} = E_{S, \text{Send}} (\text{Unicast Packet}) + \sum_{\gamma \in R_s} E_{D, \text{Recv}} (\text{Unicast Packet}) \]  

where \( R_s \) denotes the set of all nodes that can hear source \( S \), which obviously includes destination \( D \). Notice that \( TS, D \) represents an extended link cost in the sense that it accounts for the receiver energy cost of the neighboring nodes of the source that can hear the packets sent along the link between the source and the intended destination.

According to this link cost function, assuming that all candidate paths have a same hop-count, the “best” paths are those that traverse sparse areas of the network where the node density is low. For broadcast traffic, the sender listens briefly to the channel and sends data if the channel is free. If the channel is busy, the sender waits and retries later. The broadcast cost may be calculated as follows:

\[ T_{SD} = E_{S, \text{Send}} (\text{Broadcast Packet}) + \sum_{\gamma \in R_s} E_{D, \text{Recv}} (\text{Broadcast Packet}) \]  

This is not a link cost, rather it is a node cost which is assigned to sender(s) of broadcast packets. Broadcast and multicast routing algorithms may make use of this node cost to construct power-aware broadcast or multicast routing trees.
**Battery-Cost Lifetime-Aware Routing**

The main disadvantage of the problem formulation of the equation is that it always selects the least-power cost routes. As a result, nodes along these least-power cost routes tend to “die” soon by rapidly exhausting their battery energy. This is doubly harmful since the nodes that die early are precisely the ones that are most needed to maintain the network connectivity (and hence increase the useful service life of the network.) Therefore, it may be more advantageous to use a higher power cost route if this routing solution avoids using nodes that have low remaining battery energy.

This observation has given rise to a number of “battery-cost lifetime-aware routing” algorithms as described next. The *min-sum battery cost routing* algorithm minimizes the total cost of the route. More precisely, this algorithm minimizes a summation of the inverse of remaining battery capacities for all nodes on the routing path. One drawback of this algorithm is that it may select a rather short path containing mostly nodes with high remaining battery capacity but also a few nodes with low remaining battery capacity. The cost of such a routing solution may be lower than that of a path with a large number of nodes all having medium levels of remaining battery capacity. However, the former routing solution is in general less desirable from the network longevity point of view because such a path will become disconnected as soon as the very first node on that path dies.
**The min-max battery cost routing** algorithm is a modification of the minimum battery cost routing to address the above mentioned weakness. This algorithm attempts to select a route such that has the cost of the most “expensive” link (i.e., one with the minimum remaining battery capacity) on that path is minimized. Thereby, this algorithm results in a more balanced use of the battery capacity of the nodes in the network. One drawback of this algorithm is that since there is no guarantee that paths with the minimum hop-count or with the minimum total power are selected, it can select paths that result in much higher power dissipation in order to send traffic from a source to destination nodes. This feature does actually lead in shorter network lifetime because in essence the average energy consumption per delivered packet of user data has been increased.

**A conditional min-max battery cost routing:** This algorithm, which is a hybrid of the min- sum and the min-max battery cost routing algorithms, chooses the route with minimal total transmission power if there exists at least one feasible routing solution where all nodes in that route have remaining battery capacities higher than some pre-specified threshold value. However, if there is no such routing solution, then the min-max routing algorithm is employed to select a route.
3.3 IMPORTANCE OF POWER CONTROL

Transmit power control[9] is important in wireless ad hoc networks for at least two reasons: (i) It can have impact on battery life, and (ii) it can have impact on the traffic carrying capacity of the network. For the first point, note that there is no need for N1 in Figure 3.1 to broadcast at 30mW to send a packet to the neighboring N2, since N2 is within range even at 1mW.

![Diagram showing range at 1mW and 30mW](image)

**Fig.3.1 Need for Power Control**

Thus it can save on battery power. For the second point, suppose that in the same figure, 1, N3 also wishes to broadcast a packet at the same time to N4 at 1mW. If N1 broadcasts at 1mW to
N2, then both transmissions can be successfully received simultaneously, since neither is N2 in the range of its interfering N3 (for its reception from N1), nor is N4 in the range of its interfering N1. However, if N1 broadcasts at 30mW, then that interferes with N4’s reception from N3, and so only one packet, from N1 to N2, is successfully transmitted. Thus, power control can enhance the traffic carrying capacity.

The next issue that arises is: Where in the layered hierarchy does power control for ad hoc networks fit? The difficulty is that it infringes on several layers. Clearly, power control has impact on the physical layer due to the need for maintaining link quality. However, power control also has impact on the network layer, as shown in Figure 3.2 (a). If all nodes are transmitting at 1mW, then the route from node N1 to N5 is N1->N2->N3->N4->N5. However, if they all transmit at 30mW, then one can choose the route N1->N2->N5. In addition, the power control also impacts on the transport layer. In Figure 3.2 (b), every time node N1 transmits at high power to node N2, it causes inference to N3 to packet from N4. Thus there is a loss of several such packets on the link from N4 to N3. These have impact on the congestion control algorithm regulating the flow from source N4 destination N5 via the intermediate relay node N3. The need for power control is thus important today.
Fig. 3.2 Power Control Affects Many Layers
3.4 PROPOSED PROTOCOL

The protocol which is proposed is named as Power controlled – ad hoc on demand distance vector (PC-AODV). It is an extension of AODV. The difference is that it selects the route from source to destination according to the power level in the route table. The route table contains the two routes from source to destination with its power level. The algorithm chooses the route with lowest power level. It is so called because it reduces the power consumption of Network layer as well as MAC layer.

3.5 NETWORK MODEL

Power control[14] is a very complex issue, simplified it into an assignment of transmission ranges, short to as an RA problem (Range Assignment), and analyzed its computational complexity in the details. Let \( N = \{U_1, \cdots, U_n\} \) be a set of \( n \) points in the \( d \)-dimensional Euclidean space \( (d=1, 2, 3) \), denoting the positions of the network nodes and \( r(u_i) \) be the transmission radius of node \( U_i \), the network transmission power \( f[r(u_i)] \) can be expressed as:

\[
f[r(u_i)] = \sum_{u_i \in N} [r(u_i)]^\alpha
\]

(6)

Where: \( 2 \leq \alpha \leq 5 \).

RA problem is to minimize \( j[r(u_i)] \) while maintaining the network connectivity, that is:
In the one-dimensional case, (7) can be solvable in $O(n^4)$ time, while it is shown to be NP-hard in the case of the two-dimensional and three-dimensional networks. The actual power control problem is more complex than RA problem. For the RA problem, in this paper we try to reduce packets transmission power based on cross-layer to reduce network energy consumption. Assume that the link is symmetric and the maximum transmission power $P_{\text{trmax}}$ is known and the same to all nodes which are capable of changing their transmission power below it, and the relation between the power $P_i$ used to transmit packets and the received power $P_r$ can be characterized as:

$$cP_i d^{-\alpha} = P_r$$

(8)

Where, $c$ is a constant, and $\alpha$ is a loss constant between 2 and 5 that depends on the wireless medium. For Free Space propagation model and Two-Ray Ground propagation model, $\alpha$ is 2 and 4 respectively. Suppose that in order to receive a packet, the received power must be at least $\gamma$, i.e.,

$$cP_i d^{-\alpha} \geq \gamma$$

(9)

From (4) it comes out that:

$$P_i \geq \frac{\gamma}{c} T d^\alpha$$

(10)
In order to effectively support node mobility and reduce network energy consumption while simplify the network model, we only adjust the node’s transmission power in a number of different discrete power levels.

**Definitions**

In order to facilitate expression, we make the following definitions:

*Definition 1: (Power Level)* Power levels (termed as PL) are defined as the discrete grades of node transmission power. The power level between node A and node B is expressed as $\text{PL}_{(A, B)}$, the minimum power level between node A and node B is expressed as $\text{PL}_{\text{min}}(A, B)$, and the power level for a node to send data packets and MAC [11], [12] layer control packets are expressed as $\text{PL}_{\text{Data}}$ and $\text{PL}_{\text{MAC}}$ respectively.

*Definition 2: (routing selection rules 1)* If node S has k routes RT $^{(PL, h)}_{(S, D)}$ at different power levels to destination node D, then node S selects a route at the smallest power level to transmit data packets.

*Definition 3: (routing selection rules 2)* If node S has more than one route $^{(S, D)}_{(PL, h)}$ at the same power levels to destination node D, the node selects the route with the minimum hop to transmit data packets.

PC-AODV (Power controlled AODV) is an on-demand routing protocol, the essential idea is that it:
• builds different routing entries at different power levels on demand, and a node selects the route according to routing selection rules 1,2;

using different power control policies to transmit data packets as well as control packets of network layer and MAC layer.

### 3.6 POWER AND DISTANCE CALCULATION

Power level is calculated from the hello replay from neighbor nodes. Each node calculates the power for sending packets to its neighbor and adds to the neighbor table. Finally add the total power for the entire route via RREP (Route Reply) from destination to source and add to the route table. If the packet is controlled packet then it takes the maximum power (0.28183815mW) to send, otherwise it reduces the power for the data packet.

Power and Distance calculation by HELLO replay from neighbor nodes. Create a Power Table and Alter the Neighbor table, Route Establishment and Route Table Alteration. Apply Route Policies, Route Selection, and Comparison with AODV. Power is calculated from the Received Signal Strength Indicator (RSSI). RSSI is calculated by $(TrPwr*Gr*Gt*\lambda^2) /((4\pi d)^2)$. Then the RSSI is converted to the dB by the equation $10\log (RSSI/0.001)$. Then the RSSI is converted to the dB by the equation $10\log (RSSI/0.001)$.
3.7 POWER TABLE CREATION

Power in dB and distance are then compared to find the required power level.

The fuzzy logic system is used for finding the different levels.

![Fuzzy logic system for Power levels](image)

Fig.3.3 Fuzzy logic system for Power levels

The levels are VL=1, L=2, M=3, H=4 and VH=5. Then compare the calculated Power and Distance with values of each 5 levels of Fuzzy system and find the corresponding level. The level is found by the system as:

\[
f(x; a, b, c, d) = \begin{cases} 
0 & \text{for } x < a \\
(x-a)/b-a & \text{for } a \leq x < b \\
1 & \text{for } b \leq x < c \\
(d-x)/(d-c) & \text{for } c \leq x < d \\
0 & \text{for } d \leq x 
\end{cases}
\]

where \( x \) is the calculated RSSI/DIST value.
Then assign a power level value and add to power table and include a new column with the route table for power:

<table>
<thead>
<tr>
<th>Power level</th>
<th>Distance</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>0.28183815</td>
<td>0.28183815</td>
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<td>0.28183815</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
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<td>0.2</td>
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<tr>
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<td>0.1</td>
<td>0.15</td>
<td>0.28183815</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.1 Power Table**

If the packet is controlled packet, then send with maximum power. If the packet is data packet, then reduce the power to send according to the power table.

### 3.8 PC-AODV PROTOCOL

PC-AODV (Power controlled AODV) is an on-demand routing protocol. The essential idea is that it:

- building different routing entries at different power levels on demand, and a node selects the route according to routing selection rules 1,2;
- uses different power control policies to transmit data packets as well as control packets of network layers and MAC layer.

PC-AODV consists of two main phases: route discovery and route maintenance. We assume that each node uses the MAC protocol specified by IEEE 802.11 Distributed Coordination Function (DCF) which mainly uses three kinds of MAC layer control packets including
Our algorithm uses different power control strategies to transmit data packets, and control packets of network layers and MAC layer, that is, use different PLs to send network layer control packets, and the transmission power to send actual data packets is set according to the routing table entry. Furthermore, the transmission power to send MAC layer control packets is set and varied according to transmit power to send network layer control packets and actual data packets.

**Route Discovery and Maintenance**

1. *Route Discovery:*

   PC-AODV extends AODV by adding a power control metric. There are four main steps as follows in our algorithm.

   **Step 1: Determining whether there is a route to the destination node.**

   When a node S desires to send a message to destination node D, it searches the routing table firstly. If there is a valid route to the destination node D, then executes step 4, otherwise executes step 2.

   **Step 2: Establish a route to the destination node at different power levels.**

   If source node S has data packets to send and no route is known to destination node D, it immediately forwards RREQ packets at different PL = I (I = 1, 2, ..., n) to establish a route to destination node
D, where \( n \) is the total amount of power levels. Thus, form \( m \) routes \( RT^{(S, D)}_{(PL, h)} \) (\( m \leq n \)) at different power levels \( PL = I(I = n - m + 1 \ldots, n) \) from the source node \( S \) to destination node \( D \). The transmission power of the same PL route discovery is unified, and it is identical with transmission power level \( PL_{MAC} \) to send the corresponding MAC layer control packets, that is:

\[
PL_{MAC} = PL
\]

The transmission power of route discovery at different PL is not the same. The differences between single power level route discovery of PC-AODV and that of AODV are summarized as follows:

- We add PL to RREQ, RREP, ERROR and HELLO packets respectively. The transmission power level of packets is identical with their corresponding PL, while AODV has not considered power control;
- Intermediate nodes forward RREQ packets is determined on \((ID, Broadcast \ ID, PL)\), while AODV is determined on \((ID, Broadcast \ ID)\);
- PC-AODV has taken into account power control of MAC layer control packets, while AODV not..

**Step 3: Select a route to destination node according to routing selection rules 1,2.**
Let $U_{j-1} \rightarrow D$ denote a selected route by node $U_{j-1}$ to the destination node $D$ according to routing selection rules 1,2. Where node $U_j$ is the next hop of the node $U_{j-1}$ on the route from the node $S$ to the destination node $D$, $1 \leq j \leq k \leq d$, $k$ is the total number of routing hops, $d$ is network diameter, $U_0$ is source node $S$, and $U_k$ is destination node $D$. The nodes select routes to the destination node $D$ according to routing selection rules 1,2, namely: $U_{k-1}$

$$S \xrightarrow{U_0} D (S \in RT_{(S,D)}^{(U_1,D)}E, U_1 \in RT_{(S,D)}^{(U_1,D)})$$

$$U_1 \xrightarrow{U_2} (U_1 \in RT_{(U_1,D)}^{(U_1,D)}E, U_2 \in RT_{(U_1,D)}^{(U_1,D)})$$

$$\ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots$$

$$U_{k-2} \xrightarrow{U_{k-1}} D (U_{k-2} \in RT_{(U_{k-2},D)}^{(U_{k-2},D)}, U_{k-1} \in RT_{(U_{k-2},D)}^{(U_{k-2},D)})$$

$$U_{k-1} \xrightarrow{U_{k-1}} D (U_{k-1} \in RT_{(U_{k-1},D)}^{(U_{k-1},D)}, U_2 \in RT_{(U_{k-1},D)}^{(U_{k-1},D)})$$

Where

$PL_{\min}(S, U_1) \geq PL_{\min}(U_1, U_2) \geq \ldots \ldots \ldots \ldots \geq$

$PL_{\min}(U_{k-3, U_{k-2}}) \geq PL_{\min}(U_{k-2, U_{k-1}}) \geq PL_{\min}(U_{k-1, D})$

This form a route of non-increasing and minimum power levels from the source $S$ to the destination node $D$.

**Step 4 : Use different power control policies to transmit data packets and MAC layer control packets.**
After the route is established, the nodes Uj on the active route start to send data packets according to their respective routing tables, and furthermore the power level PLData to send packets is set as the same as PL of its routing table, that is:

\[ \text{PL}_{\text{DATA}} (U_i, U_j) = \text{PL} \]  \hspace{1cm} (12)

Where: node Uj+1 is the next hop of node Uj whose Power levels express as PL in its routing table, 0<= j<=k<=d, k, d, Uo and UK are the same as above mentioned parameters. Moreover, the power level PLMAC to send corresponding MAC layer control packets is consistent with PL of its routing table, that is:

\[ \text{PL}_{\text{MAC}} (U_i, U_j) = \text{PL} \]  \hspace{1cm} (13)

2. Route maintenance:

The route maintenance of PC-AODV is only suitable for active routes and is similar to AODV, which uses Hello packets and RERR packets. The differences in the process with AODV are that:

- When a node on the route monitors the route is not available, it will notify the source node S to repair the route;
- The transmission power level of the node to send Hello packets and RERR packets are set as the same as PL of the
existing effective routing table, at the same time the corresponding MAC layer control packets with the same transmission power level.

3.9 SIMULATION MODEL

In this section, we evaluate the performance of PC-AODV by Simulations. We first describe the simulation environments and performance evaluation metrics, then evaluate the performance with given environments and parameters. Finally, we show the comparisons between our scheme and AODV.

3.10 CLUSTERPOW POWER CONTROL PROTOCOL

COMPOW [9] works well if nodes are distributed homogeneously in space, but even a single outlying node could cause every node to use a high-power level. So when the spatial distribution of nodes is not homogeneous, it is obviously not optimal to use a common power level throughout the network. We might allow nodes to use a power level which depends on the destination of the packet. This suggests a simple algorithm for routing and power control in clustered networks, which attempts to maximize spatial reuse and, hence, network capacity. Every node forwards a packet to a destination using the smaller power level such that the destination is reachable, possibly in multiple hops, using only .
In some sense this is a greedy algorithm, since every node uses the lowest power level which guarantees reaching the destination according to the information it has. This is executed on the source and every intermediate node. The consequence is that if a node further downstream knows how to reach the destination using a lower power level, then it uses that lower power level for forwarding illustrates the routes chosen, and the power level used when the above algorithm, called CLUSTERPOW, is executed on a typical clustered network.

**CLUSTERPOW ARCHITECTURE AND IMPLEMENTATION**

To implement CLUSTERPOW, each node runs a routing protocol at each power level, thereby independently building a routing table by exchanging hello messages at only that power level. To forward a packet to a destination, a node consults the lowest power routing table in which is present, say, and forwards the packet at power level to the next hop indicated in the routing table.

The software architectural design of the CLUSTERPOW protocol is similar to that of COMPOW, and each node runs multiple routing daemons, one for each power level in user-space, and the routing tables constructed are made available to the CLUSTERPOW agent. The agent then populates the entries in the kernel routing table, which is the one actually consulted for forwarding packets. Each entry in the kernel routing table lists not only the next hop for that destination, but also the power level that is to be used for transmission to the next hop.
3.11 SIMULATION CONDITIONS

In the simulation, we randomly selected source node and destination node to simulate our scheme and PC-AODV on NS2[18] (Network Simulator). Detailed simulation parameters are listed below:

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS Version</td>
<td>2.34</td>
</tr>
<tr>
<td>Channel Type</td>
<td>Wireless Channel</td>
</tr>
<tr>
<td>Network Interface Type</td>
<td>Wireless Physical</td>
</tr>
<tr>
<td>Propagation Model</td>
<td>Two Ray Ground</td>
</tr>
<tr>
<td>MAC</td>
<td>802.11</td>
</tr>
<tr>
<td>Interface Queue Type</td>
<td>Queue/DropTail/PriQueue</td>
</tr>
<tr>
<td>Antenna</td>
<td>Omni Antenna</td>
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<tr>
<td>Link Layer Type</td>
<td>LL</td>
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<td>Interface Queue Length</td>
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<td>Number of Nodes</td>
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<tr>
<td>Default Data Rate</td>
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</tr>
<tr>
<td>Terrain Range (m²)</td>
<td>2000 × 2000</td>
</tr>
<tr>
<td>Routing Algorithm</td>
<td>AODV (Extended)</td>
</tr>
<tr>
<td>Packet Size</td>
<td>1024 bytes</td>
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</tbody>
</table>

Table 3.2 Simulation Parameter

3.12 PERFORMANCE METRICS

The following metrics are used to evaluate the different protocols:

Packet Delivery Ratio: This is defined as the ratio of the number of data packets received by the destinations to those sent by the sources.
• Average End-to-End Delay: This is defined as the delay between the tie at which the data packet originated at the source and the time it reaches the destination. Data packets that get lost en route are not considered. Delays due to route discovery, queuing and retransmissions are included in the delay metric.

• Network Lifetime: This is defined as the time at which the first node failure occurs, that is, the time at which some node’s energy reserve is reduced to zero.

• Network Residual Energy: This is defined as the total number of residual battery power of all nodes in the network at the time when the communication terminates.

**SAMPLE ANALYSIS**

![Sample Analysis Diagram](image)

Fig.3.4 Sample Analysis
Table 3.3 Routing table for the nodes on the route

Table 3.3 Routing table for all nodes on the route is shown in Fig.3.4. (a), the minimum PL among nodes are as follows: \( PL_{\min} (A, B) = 1 \), \( PL_{\min} (B, C) = 2 \), \( PL_{\min} (C, D) = 3 \), \( PL_{\min} (A, D) = 3 \), \( PL_{\min} (A, C) = 3 \), \( PL_{\min} (C, E) = 1 \), \( PL_{\min} (C, F) = 2 \), \( PL_{\min} (D, E) = 3 \), \( PL_{\min} (E, F) = 3 \). When the nodes have data to send, we try to establish three routes at \( PL = 1, 2, 3 \) to analyze the route discovery and route maintenance as well as data transmission process. (1) In Fig. 3.4. (a), node A is a source and node F is the destination. Node A first searches whether there is a route to the node F in its routing table, if it is made A immediately forwards actual data packs, and that the transmission power to send MAC layer control packets is the same as transmission power to send network layer control packets and actual data packets.
Otherwise, the node A must find a route to node F at PL=1 or 2 or 3 respectively. Because PL = 1 < PL_{min} (B, C) = 2 and PL = 1 < PL_{min} (A, D) = 3, node A could not find a route to node F at PL = 1. The routes at PL=2, 3 are shown in Fig. 3.4. (b), (c).

According to the routing selection rules 1, 2, A\rightarrow B\rightarrow F, B\rightarrow C\rightarrow F, C\rightarrow F nodes A, B, C and F choose a route at PL=2 to send data packets. The routing tables of nodes A, B and C are shown in Table 3.3, whose valid routes are indicated in bold font.

Throughout the transmission process of ending data packets and network layer control packets, nodes A, B, C and F use power level PL = 2. Furthermore, the power level PL_{MAC} to send corresponding MAC layer control packets is 2.

<table>
<thead>
<tr>
<th>Dest</th>
<th>Nexthops</th>
<th>Hops</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>B</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>C</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Node A Routing Table

<table>
<thead>
<tr>
<th>Dest</th>
<th>Nexthops</th>
<th>Hops</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>C</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Node B Routing Table
Table 3.4 Routing table for the nodes on the route using route selection rules 1,2

If in the route discovery process at PL = 2, node C has learnt the route to node F at PL = 1, then the route to send data packets from node A to node F consists of two parts according to the routing selection rules 1,2, as shown in Fig. 3.4. (d). And the routing tables of node A, B, C and E are listed in Table 3.4, whose valid routes are indicated in bold font. The entire route from node A to node F is **A-B-C-E-F**.

The nodes A, B and C send data packets and network layer control packets at PL= 2 in the first part, and send corresponding MAC layer control packets at PL = 2. And yet, the nodes C, E and F send data packets as well as network layer control packets at PL = 1 in the last part, and send corresponding MAC layer control packets at PL = 2. When any one of the nodes B, C, E and F monitors the route failed, it
will notify the source node A to repair it. When the source nodes find no any route at PL = 1,2,3, then they will discard the data packets.

3.13 RESULTS AND DISCUSSIONS

Simulation is performed on the basis of simulation parameters. This is performed for comparing AODV and PC-AODV algorithms to evaluate the performance.

**Average End-to-End Delay**

Fig.3.5 displays the average end-to-end delay of three algorithms with varying average traffic load. As the network average load increases, the average end-to-end delay of three algorithms increases. In Fig.6, we can see that PC-AODV provides an obvious lower network delay compared with AODV. Under the same conditions, PC-AODV can reduce the delay from 9ms to 125ms compared with other protocols. This is due to the fact that PC-AODV uses smaller transmission power.
to send data packets along the route. In wireless Ad Hoc network, use of smaller transmission power to send data packets can reduce interference and collision which benefit to decrease the retransmission, thus reduce the responding queue and transmission delay. In addition, PC-AODV can update the routing table in time in a mobile environment, and thus, reduce the queue delay. These imply that PC-AODV can improve the network delay.

**Packet Delivery Ratio**

![Packet Delivery Ratio Graph](image)

**Fig.3.6  Packet Delivery Ratio**

Fig.3.6 indicates the packet delivery ratio of two algorithms for the case when the average load varies from 1000 Kbps to 4000Kbps. For all approaches, there is a decrease in the packet delivery ratio when the load increases. The results shown in Fig.7 indicate that the packet delivery ratio of PC-AODV is higher than of AODV under the
same conditions. Since the larger the transmission range has been, the serious the local conflicts become, thus maximum power transmissions result in degradation in packet delivery ratio. As the network load increases, the probability of one successful transmission will drastically reduce. PC-AODV exploit a power control scheme, and each node tries to send data packet at a lower power level, this can reduce local conflict and improve the packet delivery ratio. By comparison with PC-AODV additionally improves the packet delivery ratio because it also considers MAC layer power control. In addition, in mobile environments, PC-AODV updates the routing table in a real time manner. Thus PC-AODV can further improve the packet delivery ratio. From these we can see that PC-AODV can increase the network packet delivery ratio, and reduce the network packet loss ratio.

**Network Lifetime and Residual Energy**

Fig.3.7 and Fig.3.8 show the network residual energy and the lifetime of two algorithms at different traffic load respectively. When there is only small traffic load, three protocols have almost achieved the same network lifetime and the residual energy. As the network average load increases, all the protocols are significantly degraded in both network lifetime and residual energy. The results in Fig.8 indicate that the network lifetime of PC-AODV is higher than AODV under the same conditions.
At the same time, the results in Fig.3.7 indicate the residual energy of PC-AODV is more than of AODV in the same circumstances. This is because AODV does not take measures to network energy consumption, and just uses the default maximum power to transmit data, consuming more energy. Some nodes of burdening heavy flow excessively consume their energy, thus the corresponding residual energy is less and the network lifetime is shortened due to uneven energy consumption.

However, PC-AODV consumes less energy because of using power control scheme. Comparing with AODV, PC-AODV further reduces network energy by integrating with MAC layer power control. These results show that PC-AODV can save the network energy consumption and prolong network.
Fig. 3.8 Network lifetime

ENHANCED OUTPUTS USING CLUSTER POWER

We have evaluated the cluster power of nodes in the wireless ad hoc networks and compared with PC-AODV and AODV.

Fig. 3.9 Comparison of Network life Time
Fig. 3.9 shows that the network lifetime comparison of Power controlled AODV with Cluster Power and AODV. The network lifetime of our proposed protocol (PC-AODV) is much better than the Cluster Power AODV and AODV. This results in higher lifetime of the network for performing routing.

**Fig. 3.10 Comparison of Network Residual Energy**

Fig. 3.10 represents that the network residual energy. This energy of of proposed protocol (PC-AODV) is compared with Cluster Power and AODV. The results shows that the improved network residual energy in the proposed Power controlled AODV when compared with Cluster Power AODV and AODV protocol.
Fig. 3.11 Comparison of Packet Delivery Ratio

Fig. 3.12 Comparison of End-to-end Delay

Fig. 3.11 and Fig. 3.12 shows the performance comparison of Power controlled AODV, Cluster Power AODV and AODV by using the performance metrics such as Packet delivery ratio, Average end-to-end delay respectively. The packet delivery ratio of PC-AODV is improved
when compared with the CPC-AODV and AODV. The average end-to-end delay of PC-AODV is reduced when compared with the CPC-AODV and AODV. So the above performance comparison shows that our proposed Power controlled ad hoc on-demand distance vector protocol performs well when compared with cluster power AODV and AODV.

3.14 CONCLUSION AND FUTURE SCOPE

We proposed an on-demand routing algorithm based on power control. This algorithm builds different routing entries according to the node power levels on demand, and selects the minimum power level routing for data delivery. In addition, PC-AODV uses different power control policies to transmit data packets, as well as control packets of network layers and MAC layer. Simulation results show that our algorithm cannot only reduce the average communication energy consumption, but also improve the packet delivery ratio and average end-to-end delay. It is a needed approach to incorporate routing protocols with power control in ad hoc networks. In future, our research will be improved on the basis of the above mentioned results. Power control is therefore a prototypical cross-layer problem affecting all layers of the protocol stack from physical to transport, and affecting several key performance measures, including the trinity of throughput, delay and energy consumption. We will incorporate it with delay, and packet loss ratio and so on to optimize network performance.
We hope that in the future studies we could not only provide multiple routings that meet the QoS requirements, but also use the compound routing that meets the QoS requirements when the single routing is not available.