CHAPTER 7

INCREASING NODE’S LIFETIME IN COOPERATIVE COMMUNICATIONS IN MOBILE AD HOC NETWORKS

7.1 INTRODUCTION

In mobile ad hoc networks, energy is an important factor that determines the lifetime of the participating node in communications. Hence, energy saving in mobile ad hoc networks is needed so that the nodes’ lifetime is increased. The Enhanced Distributed Energy-adaptive Location-based Cooperative Medium Access Control Protocol (EDEL-CMAC) is used to optimize the node’s energy efficiency in large scale MANETs. The usage of Enhanced EDEL-CMAC protocol increases the efficiency of individual nodes and entire network lifetime.

In this research work, the overheads in signal collision avoidance, transmitting power cost, data forwarding through the relay nodes and implementation complexities were concentrated in cooperative communication in MANETs. In most of the existing solutions, the CMAC protocol is used only for the improvement of throughputs and packet delivery but not for energy efficiency.

Also an Enhanced Distributed Energy adaptive Location-based Cooperative Medium Access Control protocol (EDEL-CMAC) is used to increase the energy efficiency among the mobile nodes based on the IEEE 802.11 Distributed Coordination Function (DCF) and Energy Ad hoc On Demand Vector Protocol (EAODV). EDEL-CMAC protocol includes a relay based handshaking process, a power allocation scheme, a distributed best
relay selection strategy and also an effective Network Allocation Vector (NAVs) setting.

Normally in MANET, the high diversity gains are obtained by increasing the relay node counts but specifically in MAC layer point of view, many relays lead to the enlarged interference ranges and additional control frame overheads. But in this work, a single relay node is employed to reduce the additional communication overhead. The initiation of cooperation is also done through the EDEL-CMAC and simply utilizes decode and forward protocol. The main contributions of this proposed work are as follows.

a) Proposal of a new protocol to reduce the energy consumption of mobile nodes during packet transmissions, thereby increasing the entire network life time.

b) An optimal transmitting power allocation scheme and distributed best relay selection strategy for energy savings, outage probability calculation.

c) An effective NAV setting to avoid the collisions in transmissions and to enhance the spatial reuse.

Hence the above proposed protocol will considerably increase the network lifetime under mobile environment as well as produces high throughput and low delay when compared with DCF, Energy aware Ad hoc On Demand Vector (EAODV).

7.2 EDEL-CMAC PROTOCOL

A new protocol named EDEL-CMAC is proposed to increase the network lifetime of the nodes in MANETs. Also the reservation channels are extended for space and time to coordinate the transmissions at the relay. To analyse the transmitting message relay and dynamic transmitting energy, the
Request-To-Send (RTS), Clear-To-Send (CTS), Acknowledgement (ACK) and additional control frames are required. To accommodate the cooperation, the EDEL-CMAC releases two control frames namely (i) Eager-To-Help (ETH) and (ii) Interference-Indicator (II). The ETH frame is used for selecting the best relay in a distributed manner which is sent by the winning relay.

The Interference-Indicator frame is used to reconfirm the allocated transmitting energy interference range in order to enhance the spatial reuse. Along with the RTS, CTS, ETH and ACK, the packets are transmitted with the predetermined energy. The transmitting energy for the Interference Indicator frame and the data packets are dynamically allocated. The time duration for the transmission of RTS, CTS, ETH, ACK and II frames is $T_{\text{RTS}}$, $T_{\text{CTS}}$, $T_{\text{ETH}}$, $T_{\text{ACK}}$ and $T_{\text{II}}$, respectively.

### 7.3 FRAME EXCHANGING PROCESS USING EDEL-CMAC PROTOCOL

Figure 7.1 represents the frame exchanging process of EDEL-CMAC. The RTS/CTS handshake is used to reserve the channel which is similar to IEEE 802.11 DCF protocol. The transmitting energy in cooperative transmission among mobile nodes is very small due to the additional overhead for relaying coordination overtakes energy savings in this network. This type of inefficiencies is avoided by incorporating the transmitting energy threshold “$A_p$”. The destination node computes the required transmitting energy based on the received RTS frame that the direct transmissions $E^D_s$ and it is discussed under two different scenarios.
Scenario I: The destination sends a CTS frame with flag field FLAG P equal to 0, which implies that the direct transmission is adequate. Thus, EDEL-CMAC is reduced to the DCF protocol, when the transmitting energy for the direct transmission is very low and it has backward compatibility with the 802.11 standard.

Scenario II: In CTS, the FLAG P is set to 1, all nodes are overhearing RTS and CTS, and they do not interfere with other ongoing transmissions which are considered as relay nodes. The relay nodes are checked and relay by sending ETH after a utility-based backoff, if they are able to reduce the energy consumption.

Then two relay nodes are hidden from each other, if it is out of transmission range. They can sense the message sent from each other within the sensing range. The multiple ETH frames collision due to hidden node would not exist in this type. After Short Interframe Space (SIFS), the winning relay is broadcasted and the Interference Indicator message and reconfirming the interference range of the allocated transmitting energy in relay. Then the control frames are exchanged, the source and relay nodes send the same data
frames to the desired destination in two time intervals using the specified allocated transmitting energy. Finally, the ACK is sent from the destination to source.

### 7.3.1 Energy Transmission in Source Node

When a source wants to initiate the data transmission with payload length of $L$ bytes, it first senses whether the channel is in idle state. The source selects a random backoff timer. The source sends out a RTS to reserve the channel, if backoff counter is zero. Then the location information of the source is carried in the RTS for optimal power allocation. If the source does not receive a CTS, there should be a retransmission process. Otherwise, in this type, the DEL-CMAC is reduced to DCF protocol, if the FLAG P is 0.

If FLAG P is 1, the source waits for the maximum backoff time for the relay. If both CTS and ETH are received, then the source starts a transmission with an optimal transmitting energy and the transmitting energy is piggybacked in the ETH. The doubled data rate is employed in this transmission mode in order to maintain the end-to-end throughput. If an ACK is not received, then the source would perform a random backoff like DCF. Otherwise, the transmission is successfully carried out and the source handles the next packet in the buffer.

### 7.3.2 Energy Transmission in Destination Node

Based on the received RTS, the destination node sends CTS back. The CTS contains the location information of the destination node, the FLAG P, and the transmitting energy for the direct transmission $P_D$. In this case FLAG P is 1, if the destination has not heard any ETH then the direct transmission will be performed and will wait for the data packet from the source. Otherwise, the destination will wait for the data packets from the
source to win the relay. If the destination can decode the combined signals correctly then it will send back an ACK. Otherwise it just source timeout and retransmits.

7.3.3 Relay’s Energy Transmission

Any mobile node that receives both RTS and CTS with FLAG P = 1 does not interfere with other transmissions. Based on the CTS received, each relay node checks whether it can reduce the total energy consumption by

\[ 2E_s^D E_s^c - E_r^c - 2D^1 \times (L + L_\text{h})/2R - (E_s^c + D^1) \times T \text{II} - (D + 3D^1) \times T_{\text{ETH}} > 0 \]  

(7.1)

where \( E_s^c \) and \( E_r^c \) refer to the transmitting energy for source and relay in cooperative transmission respectively. \( E_s^D \) and \( D \) refers the transmitting energy for source in direct transmission and fixed transmitting energy respectively.

Thus the \( 2E_s^D E_s^c - E_r^c - 2D^1 \times (L + L_\text{h})/2R \) represents the energy consumed in transmitting the data through cooperative communication. The term \( T \text{II} - (D + 3D^1) \times T_{\text{ETH}} \) refers the additional energy control overhead. From the equation (7.1), the relay checks whether cooperative communication reduces the total energy consumption compared with the direct transmission. Thus the best relay sends an ETH when the backoff at a better relay expires. The lost relay gives the contention when sensing ETH. The ETH has an increased transmitting energy \( E_r^c \) for source. The winning relay broadcasts Interference Indicator message through the cooperative transmitting energy at relay \( E_r^c \). It is mainly used for confirming the relay interference range to improve the spatial reuse. Hence the winning relay waits receiving the source’s data packets. Then only the received data packet is forwarded to the desired destination using the relay transmitting power.
7.4 DIFFERENT SCHEMES USING EDEL-CMAC PROTOCOL

7.4.1 Best Relay Selection Scheme

The existing relay selection schemes are incorporated into the CMAC protocols, depends on the channel condition and based on the assumption that the channel condition is invariant during one transmit session. This implies that the “best” selected relay node according to channel condition during the route construction or handshaking period will not be the best one in the actual data transmission period. Selecting the best relay node based on the instantaneous location instead of instantaneous channel condition will be more reasonable for MANETs.

In this work, a distributed energy-aware location-based best relay selection strategy is incorporated into the control frame exchanging period. The location information of individual mobile wireless devices can be obtained through GPS or other localization algorithms. The required location information of source and destination is carried by RTS and CTS frames and there is no additional communication overheads involved. EDEL-CMAC chooses the best relay based on a utility-based backoff which depends on the required transmitting energy to meet certain outage probability and individual node’s residual energy. It is done through a distributed and energy-efficient fashion, in which relay backoff. The Backoff Utility function for relay \( r \) is

\[
BU_r = \tau \min \left( E/E_r \delta \right) \times E_r^c / (E_s^D/2)
\]  

(7.2)

where \( E \) is an initial energy, \( E_r \) is current residual energy of relay \( r \), \( E_r^c \) is the transmitting energy at relay \( r \) in cooperative mode, \( E_s^D \) is the source transmitting energy \( s \) in direct mode and \( BU_r \) is short backoff time within an acceptable range. The parameter \( \delta \) is an energy consumption threshold and \( \tau \) is a constant unit time.
There is a tradeoff between the probability of collision and the time spent in the relay selection process. The value of $\tau$ cannot be made too large to postpone the time to find the best relay, or too small to raise the probability of collision. In this simulation, $\tau$ is set to 0.1 ms. The proposed strategy utilizes the location information and it takes the residual energy. It is completely distributed and every node makes the decision independently. The energy consumption rate among the nodes can be balanced based on this proposed relay selection strategy.

### 7.4.2 Efficient Power Allocation Scheme

Optimal power allocation scheme aims at increasing energy efficiency for the entire network. The power allocation for Cooperative Communication and direct transmission under the given outage probability is addressed clearly in this work. The source transmitting energy in the direct transmission mode is calculated by the destination node once it receives the RTS. Then, the optimal source transmitting energy and also the relay transmitting energy in the cooperative transmission mode is calculated through the individual relay nodes based on the same outage probability and end-to-end data rates.

### 7.4.3 Direct Transmission

In order to meet an outage probability $P_D^o$, the minimum transmitting energy in the direct transmission mode is given as

$$E_s^D = - \frac{(2R-1)}{N_0 d_{sd}^a} \frac{1}{\ln(1-P_D^o)}$$

(7.3)

where $R$ is the transmission rate, $d_{sd}^a$ is the distance between the source and destination, $\alpha$ is the path loss exponent, $N_0$ is noise component variance.
7.4.4 Cooperative Transmission

The optimal power allocation for cooperative transmission exists when the source transmitting energy $E^c_s$ equals the transmitting energy in relay $E^c_r$. The $E^c_s$ is the solution which is expressed as

$$d_{sd}^\alpha G(d_{sd}^\alpha + d_{rd}^\alpha) - d_{rd}^\alpha G(d_{sr}^\alpha + d_{sd}^\alpha) + (1 - P_c^0)(d_{rd}^\alpha - d_{sd}^\alpha) = 0$$  \hspace{1cm} (7.4)

where $G(d) = \exp(-(2^{2R}-1)N_0d/E_s)$

In Equation 7.4, $d_{sd}$ is the distance between the source and destination, $d_{rd}$ is the distance between relay node and destination node, $d_{sr}$ is the distance between the source and relay node, $P_c^0$ refers to outage probability of cooperative node and $\alpha$ is the path loss exponent.

7.4.5 Spatial Reuse Enhancements

The involvement of relaying and varying transmitting energy, the interference range in EDEL-CMAC are changed during one transmit session. To avoid the interference and optimize the energy consumption, mild and different NAV settings are required. NAV limits the use of physical carrier sensing, thus conserves the energy consumption.

The nodes listening on the wireless medium read the duration field in the MAC frame header, and set their NAV on how long they must defer from accessing the medium. Taking IEEE 802.11 DCF for instance, the NAV is set using RTS/CTS frames no medium access is permitted during blocked NAV durations. Comparing with the different NAV setting in DCF, the setting in EDEL-CMAC needs to be considerably modified. The presence of
relays will increase the interference ranges and the dynamic transmitting energy makes the interference ranges vary during one transmit session. If NAV setting is wrong then it induces energy waste and collisions.

Specifically, setting the NAV duration too short will wake up the node too soon, which results in energy waste due to medium sensing. On the other hand, setting it too long will reduce the spatial efficiency, which results the performance degradation in throughput and delay.

Thus, an optimal NAV setting needs to be incorporated to reduce the energy wastage and collisions which leads the enhancement in nodes’ lifetime of this network. Most of the previous works did not address the NAV setting issue in cooperative communications. In Figure 7.2, the specific NAV setting for proposed in EDEL-CMAC is addressed in different steps (regions).

**Step 1:** According to our EDEL-CMAC, nodes are contending for the winning relay after the RTS/CTS exchange. All lost relays should keep silence until the whole transmit session is finished based on receiving ETH. Notice that for the sake of the relay selection, the node cannot set their NAVs and they receive the RTS as in the IEEE 802.11 DCF. All the neighbouring nodes have to wait until the end of the CTS.

**Step 2:** The node receives the RTS but not CTS. Those nodes set their NAV durations until the end of the ACK.

\[ T_{\text{Backoff}}^{\text{MAX}} + T_{\text{ETH}} + T_{\text{II}} + T_{\text{ACK}} + (16L(L+L_h)/2R) + 5\text{SIFS} \]  

(7.5)

Thus, the NAV duration in step 1(region) is

\[ T_{\text{II}} + T_{\text{ACK}} + (16L(L+L_h)/2R) + 4\text{SIFS} \]  

(7.6)
**Step 3:** The node receives the CTS but not the RTS then they set their NAV until the end of the ACK.

**Step 4:** According to different transmitting energy, the transmission ranges at the relay for the ETH message with fixed transmitting energy (Figure 7.2). The transmission range for the interference indicator message and data will allocate transmitting energy of the node. The nodes in steps 4 falls inside the small transmission range at the relay and they should defer the medium access until the end of the data transmissions.

In 802.11 DCF, the nodes outside the transmission ranges of source and destination do not set NAV, they use physical carrier sensing to avoid the collision. Thus, the different NAV setting in EDEL-CMAC, the NAV duration for nodes in step 4 ends before the ACK frame. The duration of NAV is

\[(16L(L+L_d)/2R) + 2\text{SIFS}\]  

(7.7)

![Figure 7.2 NAV Setting in EDEL-CMAC](image)
Step 5: The terminals can receive the ETH but not the Interference Indicator. The nodes in this region fall inside the large transmission range at the relay. Those nodes have a relatively short NAV duration comparing to the nodes in steps 4, which is only $8L(L+L_h)/2R$. When the source finishes its data transmission, the nodes in steps 5 and the relay will not interfere with each other.

On basis of utilizing interference indicator frame, the nodes in this step 5 will initiate their transmission in advance and given they are outside the interference range of destination.

7.5 ENERGY SAVINGS USING EDEL-CMAC PROTOCOL IN LARGE SCALE MANET

In this network, a distributed best relay selection approach is incorporated for best relay, location information and residual energy consumption. In addition to this, an innovative and different network allocation vector (NAV) is involved for relaying and varying transmitting energy. The interference range in EDEL-CMAC are changed during one transmit session. In order to avoid the interference and save the energy, mild and different NAV setting is required. NAV limits the use of physical carrier sensing, thus conserves the energy consumption.

Comparing with the different NAV setting in Distributed Coordination Function (DCF) and Energy Ad hoc on Demand Vector Routing (EAODV), the settings in EDEL-CMAC needs to be considerably modified. If NAV setting is wrong, then it induces energy waste and collisions. The setting is too long, it results in decreasing the throughput and increasing delay. So, the NAV settings are set in this research work that produced the results as follows.
7.6 RESULTS

In this proposed energy efficiency work, the large scale networks are considered and various iteration processes was carried out using Network Simulator Tool NS2. This proposed work is simulated with parameters shown in Table 7.1 to achieve the better performance in cooperative packet delivery and increased nodes' lifetime.

The individual node energy consumption of EDEL-CMAC protocol is comparatively less than EAODV protocol which it is shown in Figure 7.4 and denotes the transmitting energy to satisfy different outage probability requirements, when the distance among the source and destination is 50 m. It directs that high outage probability requirement leads to high cost in terms of transmitting power.

Table 7.1 Simulation parameters for EDEL-CMAC Protocol

<table>
<thead>
<tr>
<th>Channel TYPE</th>
<th>Wireless Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propagation</td>
<td>Two Ray Ground</td>
</tr>
<tr>
<td>Antenna Type</td>
<td>OmiAntenna</td>
</tr>
<tr>
<td>Routing Protocol</td>
<td>EDEL-CMAC</td>
</tr>
<tr>
<td>X value</td>
<td>1800m</td>
</tr>
<tr>
<td>Y value</td>
<td>1000m</td>
</tr>
<tr>
<td>Queue length</td>
<td>10000</td>
</tr>
<tr>
<td>No. of packets</td>
<td>75</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>100 Jouls</td>
</tr>
<tr>
<td>Packet Type</td>
<td>CBR</td>
</tr>
</tbody>
</table>
The transmitting power for EDEL-CMAC cooperative transmission is far less than the one for EAODV (Energy Adaptive On Demand Vector Protocol). In Figure 7.3, the total energy consumption is compared in one transmit session. The ratio of the energy consumption on transceiver circuitry to transmit amplifier is \( (D^1/D)^{0.5, 1} \). The energy consumption at different distances for different \( (D^1/D) \) ratio is plotted.

The energy consumption of EAODV is dramatically increased as the distance increases. The energy cost by EDEL-CMAC remains in the same level even for farther distances. The energy consumption of EDEL-CMAC is significantly below EAODV for medium to long distances at both sender and receiver.

![Figure 7.3 Transmitting Power Vs Outage Probability](image)

**Figure 7.3 Transmitting Power Vs Outage Probability**
From Figure 7.6, the node area is randomly deployed in a square area of 1800×1000m$^2$ and the Constant Bit Rate (CBR) connections between the source and destination. The performance over EAODV rises as the number of node increases. i.e., If the node density is low some nodes have to play the role as the source and cooperative relay alternately. Next if the node density is high that the relay nodes are placed in the ideal positions.

This work also investigates the effect of nodes’ mobility to fit the random waypoint model in this simulation. Each node chooses a random position, and move towards a direct line at a constant speed which is picked randomly from a range. The maximum speed is set at 10mps and the pause time at 10s.
Figure 7.5 Network Lifetime Vs Node Density in a Mobile Environment

Our EDEL-CMAC lengthens the network lifetime by at least 2 and 4.8 times for \((D^1/D) = 0.5\), and 1.3 and 2.8 times for \((D^1/D) = 2\). Hence from the Figure 7.6, it is observed that the EDEL-CMAC performs mobile scenarios in terms of entire network lifetime.

Figure 7.6 represents the delay performance between the EDEL-CMAC protocol and EAODV protocol. In Figure 7.7 the throughput performance between the EDEL-CMAC and EAODV protocol in mobile environment is shown.

Figure 7.6 Delay Performance Vs Node Density in Mobile Environment
The performance of EAODV decreases considerably in the mobile scenario, since the table-based proactive relay selection will not adapt to the moving networks. The throughput of entire network in EDEL-CMAC, increases by 4.04% in mobile environment when compared with EAODV and the delay decreases by at most 3.93% in mobile environment. With this network lifetime, providing the cooperation based on high throughput, less delay are also the important factor when large numbers of nodes are participated in communication.

In this research work, an Enhanced Distributed Energy-adaptive Location-based Cooperative MAC protocol is proposed for large scale mobile ad hoc network and implemented to minimize the transmitting energy by the effective relay selection strategy that selects the best relay terminal. The optimal power allocation scheme and enhanced spatial reuse using NAV settings are analysed for increasing nodes’ lifetime in order to avoid collisions in a mobile environment.
This simulated work using EDEL-CMAC protocol shows that the lifetime of nodes are increased in entire networks and effectively transmits the packets with good performance. The results obtained from our experimentation shows that the proposed protocol proves to be more effective when compared with existing techniques.

7.7 SUMMARY

In this research work, EDEL-CMAC protocol was utilized to increase the energy efficiency in cooperative communication. It reduced the energy consumptions of participating mobile nodes in the entire network and improved the throughput to lead the cooperative communications in MANETs. The effective relay selection strategy and Network Allocation Vector (NAV) settings were included in this cooperative energy consumption among the nodes.

The different NAV settings were applied in a different sessions with DCF, EAODV and EDEL-CMAC for manipulating the transmitting energy at relay nodes while the transmissions. The minimum energy transmission costs of this EDEL-CMAC protocol was less, when compared with other incorporated energy transmitting cost of DCF and EAODV.