CHAPTER 5
CHAPTER 5
POWER MONITORING ALGORITHM (PMA)

The proposed algorithm of online power monitoring is presented in previous chapter. This algorithm is focused to provide an efficient mode of communication in wireless network based on multi-hop communication. The algorithm is observed to be effective in communication when the data are transferred over the wireless channel based on the link status. The packets are forwarded only when the link has the capacity of handling it, the congestion is observed to be very minimal. As the above stated approach provides a link optimization approach to improve network capacity, a per node power monitoring algorithm (PMA) is proposed which reduces the power interference based on multi access power per node. The approach of monitoring power per node is presented in following section.

5.1 PROTOCOL DESIGN

The proposed protocol is developed for contention based routing scheme using modified CTS reservation mechanism. The CTS packets are transmitted over the control channel at a fixed maximum power Pmax. All potentially interfering nodes, as in the IEEE 802.11 scheme [61][62], receive these packets. However, in contrast to the IEEE 802.11 scheme protocols [61][62], interfering nodes may be allowed to transmit
concurrently, depending on some criteria. For the ensuring data packet, the receiver and the transmitter must agree on two parameters: the source code and the transmission power. Code selection can be done according to any code assignment scheme. The choice of the power level is critical and represents a tradeoff between link quality and MAI. More specifically, as the transmission power increases, the bit error rate at the intended receiver decreases (i.e., link quality improves), but the MAI added to other ongoing receptions increases (i.e., the quality of these receptions deteriorate). In addition to accounting for these two factors, this protocol incorporates an interference limit in the power computations.

This limit allows terminals at some interfering distance from the intended receiver to start new transmissions in the future. In this design, two frequency channels were used, one for data and one for control (i.e., FDM-like partitioning). All nodes use a common spreading code over the control channel, while several terminal-specific codes can be used over the data channel. The different codes used over the data channel are not perfectly orthogonal. However, because of the frequency separation, a signal over the control channel is completely orthogonal to any signal (or code) over the data channel. The splitting of the available bandwidth into two non-overlapping frequency bands is fundamentally needed to allow a terminal to transmit and receive simultaneously over the control and data channels, irrespective of the signal power.
5.2 MAI INTERFACE IN WIRELESS NETWORK

In the uplink of a wireless communication system, the near-far problem is combated through a combination of open- and closed-loop power control, which ensures that each mobile terminal generates the same signal power at the base station. The base station monitors the received signal power from each terminal and instructs faraway terminals to increase their signal powers and close by terminals to decrease theirs. Unfortunately, the same solution cannot be used in distributed random network. For example, considering the situation as shown in Figure 5.1., let $d_{ij}$ denote the distance between nodes i and j. Suppose that A wants to communicate with B using a given code and C wants to communicate with D using a different code. Suppose that $d_{AB} \approx d_{CD}$, $d_{CB} - d_{AB}$, and $d_{AD} - d_{CD}$. Then, the MAI caused by C makes it impossible for B to receive A’s transmission. Similarly, the MAI caused by A makes it impossible for D to receive C’s transmission. It is important to note that the two transmissions cannot take place simultaneously, irrespective of what transmission powers are selected (e.g., if A increases its power to combat the MAI at B, then this increased power will destroy the reception at D).

![Diagram of nodes A, B, C, and D with distances and MAI intersections.]
The above example reveals two issues. First, it may not be possible for two transmissions that use two different power levels to occur simultaneously. Obviously, this is a medium access problem. Second, the two transmissions can occur simultaneously if the terminals adjust their signal powers so that the interference caused by one transmission is not large enough to destroy packet reception at other terminals. Obviously, this is a power control problem. So the solution to the near-far problem has to have both elements: power control and medium access.

The monitoring algorithm is responsible for minimizing or eliminating collisions, thereby, achieving good utilization of the available bandwidth. The use of the monitoring algorithm implies that even if a terminal has an available limit, it may not be allowed to transmit until MAI is tolerated. The design of the proposed protocol is as described in subsequent sections, with the following objectives:

- The protocol must be asynchronous, distributed, and scalable for large networks. It must also involve minimal exchange of information and must be suitable for real-time implementation.
- The receiver circuitry should not be overly complex in the sense that it should not be required to monitor the whole code set.
- The protocol should adapt to channel changes and mobility patterns.
The protocol is running at a higher layer, so, the monitoring algorithm must minimize (or eliminate) collisions even if the assignment is not “correct”. This is important because it is usually difficult to guarantee correct power assignment at all times when network topology is continuously changing.

5.3 POWER MONITORING ALGORITHM

In general, a terminal with a brute cast packet can proceed immediately with its transmission, starting with a demand / exchange CTS, regardless of the channel. Under appropriate monitoring schemes, conventional protocols are guaranteed to be free of primary collisions. However, due to the nonzero cross-correlations between different data transmitted cause interference with multiple entry (Mai), resulting in secondary collisions at a receiver, this problem is known as a problem by -away. Near-far problem can cause a significant reduction in network throughput, and thus cannot be overlooked. To achieve significant improvement in network performance in this protocol, the transmission powers are dynamically adjusted to (Mai) such that every receiver is not strong enough to trigger a secondary collision. This results in a significant improvement in network throughput at no additional cost in energy consumption. In fact, the proposed protocol is shown to achieve some energy saving schemes, compared with 802.11.
Figure 5.2 Flowchart of power monitoring system

1. START
2. Generate REQ packet with current offered node power TP
3. If TP < TPTH (CST)
   - Forward the packet to channel at sink
4. If received power <= Tx Power
   - Absorb the packet
5. From all neighbour communicating nodes
6. Recode TP
7. Compute total TP at the Sink
8. Check for limits of MAI
9. If TP is in limits of MAI Value
   - Acknowledge source with forward signal='0'
10. Acknowledge source with forward signal='1'
11. END
5.4 INTERFERENCE LIMIT

An interference limit is needed to allow terminals at some distance from a receiver to start new transmissions in the future. This limit is computed as presented below;

For an arbitrary receiver i, let μ' be the Eb/No ratio, that is needed to achieve the target bit error rate at that receiver. It follows from that to achieve the target error rate, we must have

\[
\frac{P_{i\text{Eb}}}{P_{\text{thermal}} + P_{\text{MAI}}} \geq \mu' \tag{5.1}
\]

where \(P_{\text{thermal}}\) is the thermal noise power and \(P_{\text{MAI}}\) is the total MAI at receiver i, so the minimum required received power is \((P(i))_{\text{min}} = \mu'(P_{\text{thermal}} + P(i)*\text{MAI})\).

The interference limit strongly depends on the network load, which itself can be conveyed in terms of the so-called noise rise \((\xi(i))\), defined as follows:

\[
\xi(i) \equiv \frac{\frac{E_b}{N_0} \text{unknown}}{\frac{E_b}{N_0} \text{loaded}} = \frac{P_{\text{thermal}} + P_{i\text{MAI}}}{P_{\text{thermal}}} \tag{5.2}
\]

\((P(i))_{\text{min}} = \xi(i)\mu'P_{\text{thermal}}\) is also dependent on the noise rise. While more capacity can be achieved by increasing the noise rise (i.e., allowing larger \(P(i)\ \text{MAI}\)), the maximum allowable noise rise is constrained by two factors. First, the regulations limit the power to a fixed value i.e., 1 Watt for 802.11 devices. Given this maximum transmission power, as the noise rise is increased, the received power \((P(i))_{\text{min}}\) must increase (as \(\mu'\)
and $P_{\text{thermal}}$ are constants) and hence, the maximum range (or coverage) for reliable communication will decrease. Second, increasing the noise rise increases the power used to transmit the packet, which in turn increases energy consumption. Energy is a scarce resource in W-NET, so it is undesirable to trade off energy for throughput. We set the interference limit used by a transmitter to the maximum planned noise rise ($\xi_{\text{max}}$), which is obtained by taking into account the above two restrictions on $\xi(i)$.

The admission scheme allows only transmissions that cause neither primary nor secondary collisions to proceed concurrently. The CTS fields are used to provide three functions. The format of the Requesting packet is similar to that of the IEEE 802.11 [61][62], except for an additional two-byte field that contains the $P(j)$ value. The format of the requesting packet is as shown in figure 5.3.

![Format of a requesting packet.](image)

Figure 5.3: Format of a requesting packet.

These packets allow nodes to estimate the channel gains between transmitter-receiver pairs. Second, a receiver $i$ uses the CTS packet to notify its neighbors of the additional noise power (denoted by $P(i)$ noise) that each of the neighbors can add to terminal $i$ without impacting $i$’s
current reception. These neighbors constitute the set of potentially interfering terminals. Finally, each terminal keeps listening to the control channel regardless of the signal destination in order to keep track of the average number of active users in their neighborhoods.

### 5.5 Communication Operation

The process of packet transfer over the network is explained as follow. If a terminal $j$ has a packet to transmit, it sends a requesting packet over the control channel at $P_{\text{max}}$, and includes in this packet the maximum allowable power level ($P(j)$) that terminal $j$ can use that will not disturb any ongoing reception in $j$’s neighborhood. Upon receiving the requesting packet, the intended receiver, say terminal $i$, uses the predetermined $P_{\text{max}}$ value and the power of the received signal $P(j_i)$ received to estimate the channel gain $G_{ji} = P(j_i) \text{ received}/P_{\text{max}}$ between terminals $i$ and $j$ at that time. Terminal $i$ will be able to correctly decode the data packet if transmitted at a power $P(j_i)_{\text{min}}$ given by:

\[
P(j_i)_{\text{min}} = \frac{\mu^* (P_{\text{thermal}} + P_{\text{Mai-current}})}{G_{ji}}
\]

Where $P_{\text{Mai-current}}$ is the effective current from all already ongoing transmissions. Because of the assumed stationary in the channel gain over small time intervals, $G_{ji}$ is approximately constant throughout the transmissions of the control packet and the ensuing data packet. Now, $P(j_i)_{\text{min}}$ is the minimum power that terminal $j$ must use for data
transmission in order for terminal \( i \) to correctly decode the data packet at the current level of interference. This \( P_{ij}^{\min} \), however, does not allow for any interference tolerance at terminal \( i \), and thus all neighbors of terminal \( i \) will have to defer their transmissions during terminal \( i \)'s ongoing reception (i.e., no simultaneous transmissions can take place in the neighborhood of \( i \)). The power that terminal \( j \) is allowed to use to send to \( i \) is given by:

\[
P_{ij}^{\text{allowed}} = \frac{\xi_{\text{max}}^2 P_{\text{thermal}}}{c_R}
\]

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5.4

If \( P_{ij}^{\text{allowed}} < P_{ij}^{\min} \), then the MAI in the vicinity of terminal \( i \) is greater than the one allowed by the link budget. In this case \( i \) responds with a negative CTS, informing \( j \) that it cannot proceed with its transmission. This is to prevent transmissions from taking place over links that provide high MAI. This consequently increases the number of active links in the network (subject to the available power constraints). On the other hand, if \( P_{ij}^{\text{allowed}} > P_{ij}^{\min} \), then it is possible for terminal \( i \) to receive \( j \)'s signal but only if \( P_{ji}^{\text{allowed}} \) is less than \( P_{ji}^{\min} \) (included in the requesting). This last condition is necessary so that transmitter \( j \) does not disturb any of the ongoing transmissions in its vicinity. In this case, terminal \( i \) calculates the interference power tolerance \( P_{i}^{\text{MAI-future}} \) that it can endure from future unintended transmitters. This power is given by,

\[
P_{i}^{\text{MAI-future}} = \frac{3W \sigma_{ji}^2}{2 \mu^{\text{c}}} \left( P_{\text{allowed}}^{ji} - P_{\min}^{ji} \right)
\]

---

5.5
The factor $3W/2$ comes from the spreading gain. The next step is to equitably distribute this power tolerance among future potentially interfering users in the vicinity of $i$. The objective behind this distribution is to prevent one neighbor from consuming the entire $P_{Mai}\_future$.

The distribution of this power tolerance is given as:

If terminal $i$ keeps track of the number of simultaneous transmissions in its neighborhood, donated by $K_{inst}^{(i)}$. Monitored by the requesting/CTS exchanges over the control channel. In addition, $i$ keeps an average $K_{avg}^{(i)}$, (avg of $K_{inst}^{(i)}$) over a specified window. The, $K^{(i)}$ is calculated as:

$$K^{(i)} = \begin{cases} \beta \left( K_{avg}^{(i)} - K_{inst}^{(i)} \right), & \text{if } K_{avg}^{(i)} > K_{inst}^{(i)} \\ \beta, & \text{otherwise} \end{cases}$$

where $\beta > 1$ is a safety limit.

While communication it is observed that when the within interference is more than the neighbor interference the level of effect observed is high to reduce this interference effect the neighbor interference is to be reduced.

On the calculation if the average interference levels per node the CTS packets are generated with the available interference limit with the required power transmission request to the neighboring node as shown in figure 5.4.

Figure 5.4: Format of the CTS packet in the proposed algorithm.
This demanded power Derived from the CTS packet is then compared with the available power limit and transmitted back for acceptance over the control channel to forward the packet. In case the requested power is more than the limiting power the request is denied.

A summarized format of the proposed communication algorithm is as presented below;

To monitor the per node power interference, the Power Monitoring algorithm is developed with an updated requesting packet, An additional field of current node power is added to the conventional request frame to exchange the current power reference of the source node.

For a distributed network,

- Generate a request packet with current offered node power $T_p$, due to all its neighboring communicating nodes.
- Forward the request packet to the channel if $L_p < L_{pth}$ At sink,
- If the received packet is in transmitted power value, absorb the information.
- Decode the transmitted power field $T_p$ from the request field,
- Compute the local $T_p$ at the sink due to each neighbor links.
- If current node $T_p$ is in limit to MAI acknowledge the source with forward signal =’1’ else ‘0’.
- If forward signal is observed high source forwards data packet.

This proposal contributes in reducing MAI at node due to simultaneous transmission.
• As in conventional approaches irrespective of per node offered power each individual node observes the offered load as its own load.
• Whereas from sink side the offered link power is sum of all successive \( L_p \)
• During communication as the forwarding of packet is controlled by the CTS packet of the receiver unit offered power load at the sink is controlled.
• The sink node based on its current offered power load allows or reject the packet reception and also generation, hence resulting in reducing MAI and network overhead in the network.

Additional to the stated two approaches the quality factor of the transmission and reception is also considered. As in wireless node power are constraint running of heavily computing estimating algorithms may not be suitable. As these algorithm leads to early drain of battery power, a simple but efficient approach of data transfer is developed.

In the 802.11 protocol [61][62], Virtual sensing is done by employing a request/CTS exchange before transmitting a unicast data packet. The physical carrier sensing is done by using the clear channel assessment (CA). Wireless network handles physical carrier sensing by using the CST. However, as explained, wireless network is incapable of cumulative received power tracking. Thus, in wireless network the wireless medium is reported as busy when received power of a single
packet is higher than CST. A carrier sensing system which compares the
total received power at the wireless point by a power threshold is
implemented. In the original implementation, physical carrier sensing is
handled by a timer. When there is a packet with a received power higher
than CST the timer is set to the end of that packet’s transmission. So,
when the packet’s transmission ends, the MAC layer switches to idle
state assuming no other packet is currently being transmitted or received
and RTS/CTS option is turned off. This implementation is modified in the
following way:

1 When a packet with a received power higher than CST arrived at the
node the timer is set just like in the original code.

2 When this timer expires, the MAC layer checks if the total received
power level at the node is lower than CST. If it’s lower, the wireless
medium is indicated as idle.

3 If the total received power at the node is still higher than the CST, the
medium cannot be indicated as idle until the total received power drops
below CST. In order to check if this is the case, after the ending of every
single packet’s transmission the node compares the total received power
to the CST. The simulation observations over the created network using
the suggested approach is presented below, the throughput parameters of
the developed system under different data rate is observed.
Figure 5.5: Throughput for transmit power $P_t=10$dBm with 512-byte packet

<table>
<thead>
<tr>
<th>Time (Sec)</th>
<th>Throughput(Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Mbps</td>
</tr>
<tr>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.1: throughput observation over variable offered data rate wrt. time variation.

A simple simulation involving just two nodes one transmitter and one receiver with $P_t = 10$ dBm. With 512 bytes packets, the throughput at 1Mbps makes a sharp transition at $t = 140$ m. The sharp transition is seen at various distances depending on the data rate. This is because of the fact that the definition of range depends on the data packet length.
For a 1500 bytes packets the SINR required for all the bits to be correct is higher than the 512 bytes packets case.

![Transmit Power vs Range Plot at Variable Noise Level](image)

**Figure 5.6:** transmitted power v/s range plot at variable noise level

<table>
<thead>
<tr>
<th>Transmit power(dbm)</th>
<th>Transmit range</th>
<th>Cs range for CST=-84 dbm</th>
<th>Cs range for CST=-81 dbm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>200</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
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<td>25</td>
<td>320</td>
<td>420</td>
<td>470</td>
</tr>
</tbody>
</table>

**Table 5.2:** Range observed over transmitted power

For the observations obtained for the transmitted power at CST= -84 dBm, the packet delivery ratios for source routing and demand routing protocol are observed very similar with transmit power $P_t$ higher than 16 dBm. When the transmit power is lower than 16 dBm, demand routing protocol outperforms source routing in terms of packet delivery ratio.
However at any transmit power, source routing demonstrates significantly lower routing load than demand routing protocol. This is due to source routing's aggressive use of route caching. Source routing is likely to find a route in the cache and avoid using route discovery every time a link is broken. Demand routing protocol also features timer-based states in each node. A routing entry is deleted if it not used during a specified amount of time. On the other hand, source routing keeps the routing entries in the cache until a link on the route is found to be broken.