Wireless Sensor Network (WSN) is a sub-class of ad hoc networks that are infrastructure-less networks in which the nodes are capacitated with network initialization and maintenance operations apart from the intended data communication operations. The immense overhead of such self-organizing networks demands a high energy consumption in every node and the added challenge is that the wireless nodes often find it difficult to replenish the battery power in many network scenarios. Thus, energy efficiency helps to increase the device’s lifetime and maintain the network topology. Energy efficiency in WSN can be achieved in every layer of the protocol stack starting from the physical layer up to the application layer.

The objective of the present work is to establish energy efficiency in WSN by minimizing the transmission power in the Medium Access Control (MAC) layer while maintaining maximum throughput. A wireless node consumes two types of power: computation power and transmission power. It is proven that more power is consumed for transmission than for computation. In most of the commercial sensor nodes, thousands of instructions can be executed using the power consumed per transmission bit. Hence, Transmission Power Control (TPC) algorithms are investigated in this research work with two approaches, namely: location based TPC algorithms and Received Signal Strength Index (RSSI) based TPC algorithms.

Location based TPC algorithms use the distance of separation between a transmitter-receiver pair for deciding the required transmission power ($P_{\text{req}}$) required for maintaining the RSSI just above the threshold level at the receiver. Three algorithms are proposed in this method. Location aided TPC
algorithm (LATPC) uses the location information of the nodes and a known channel model to decide the transmission power. The algorithm works effectively when the channel characteristics are modeled exactly by a deterministic equation relating the transmitted and received power values and when every node knows the current location of every other node in the network. Location Prediction based TPC ALGORITHM (LPTPC) assumes a known channel model but does not use the location information of the nodes. It uses the transmission power of the source node \( P_{\text{src}} \) and the observed RSSI at the receiver to assess the location, i.e., the distance \( d_{\text{assess}} \) between the transmitter and receiver using the assumed fixed channel model. Using the \( d_{\text{assess}} \) value, the required transmission power \( P_{\text{req}} \) is calculated using the same channel model. The algorithm works well when the assumed channel model characterizes the actual channel accurately. TPC algorithm based on Location Prediction using Markov model (LPMTPC) assumes that both the location information and the channel characteristics are unknown. The WSN is modeled as a discrete time Markov chain for predicting changes in the distance of separation \( \hat{d}_d \) between the transmitter-receiver pair. The predicted \( \hat{d}_d \) information and the current RSSI information are given as inputs to a Fuzzy Logic Controller (FLC) which decides the \( P_{\text{req}} \) value. LPMTPC algorithm reduces the average power and also brings down the number of dropped packets considerably for a chosen network scenario under both noiseless as well as noisy channel conditions. However, it is observed that all the location prediction methods utilize the observed RSSI values, for deriving the distance information in order to calculate the required transmission power. Hence, RSSI can be directly considered for TPC algorithms instead of deriving the distance information from it for calculating.
RSSI based TPC algorithms are simpler to design and implement than the location based TPC algorithms as they depend on the RSSI values that are measured directly from the received packets. Four algorithms are proposed in this approach. RSSI based TPC algorithm using Simple Mapping (SMTPC) accumulates the average values of RSSI and LQI over a time period \( t \) and determines \( P_{\text{treq}} \) using a simple mapping between the two inputs (RSSI and LQI) and the output \( P_{\text{treq}} \). In case of Frame Errors greater than 5% in the observed time period \( t \), the power level is incremented by one step. SMTPC algorithm offers a good saving in average power when compared to the unmodified IEEE 802.15.4 MAC standard. However, the abrupt switching from one range to the next in the mapping method leads to an inefficient TPC algorithm. Fuzzy Logic based TPC algorithm using RSSI and LQI (FTPC1) is an improvement to SMTPC algorithm. It uses the observations of RSSI and Link Quality Index (LQI) to design an FLC block for deciding the \( P_{\text{treq}} \). This ensures a smooth transition between the ranges for the inputs as well as the output. Hence, the efficiency of the TPC algorithm is improved when compared to SMTPC algorithm. Modified Fuzzy Logic based TPC algorithm using RSSI and \( P_{\text{tsrc}} \) (FTPC2) offers an improvement over FTPC1 as it uses the value of transmission power used at the source node \( P_{\text{tsrc}} \) along with RSSI as inputs for the FLC. The use of \( P_{\text{tsrc}} \) instead of LQI provides an opportunity for better control of \( P_{\text{treq}} \) than FTPC1. Enhanced Fuzzy logic based TPC algorithm with Markov model for RSSI prediction (EFTPC) is an enhancement for FTPC2 algorithm in order to reduce the dropped packets. EFTPC algorithm uses a Markov model to predict the future RSSI variations \( \delta_t \) in the same way \( \delta_d \) is predicted in LPMTPC algorithm. EFTPC algorithm
has an advantage that \( \hat{\delta}_r \) predictions are more accurate than \( \hat{\delta}_d \) as the predictions are based on the directly measured RSSI values.

The performance of the three different location based TPC algorithms and four different RSSI based TPC algorithms proposed in the present work is analyzed using the performance parameters namely: (i) average power (ii) average energy per successful transmission and (iii) throughput. LATPC algorithm with a deterministic channel model and known node locations creates an ideal atmosphere under noiseless channel conditions and hence offers the best performance. For a 128-node WSN, it uses the least average power of -6.883 dB and the least energy of 0.35 mJ per successful transmission. However, a practical WSN is implemented under fading channel conditions with unknown channel characteristics and unknown location information. Under such conditions, LATPC algorithm cannot be used. In such a scenario, EFTPC algorithm outperforms all other TPC algorithms proposed in this research work, with the least average power of -3.916 dB and the least energy of 0.473 mJ per successful transmission. It also offers the highest throughput among all the TPC algorithms.

EFTPC algorithm is also compared with a TPC algorithm called FCTP algorithm proposed in the recent literature. It is observed that EFTPC algorithm performs superior to FCTP algorithm and uses only 50% of the average power and average energy used by FCTP algorithm. It also offers 37% more throughput than the FCTP algorithm. Thus, EFTPC algorithm offers the best performance in terms of least average power, least average energy and highest throughput among all the TPC algorithms proposed in this research work and also FCTP algorithm proposed in recent literature.