CHAPTER 1
INTRODUCTION

1.1 GENERAL

Wireless communication has been experiencing its fastest growth period in history, due to enabling technologies which permit widespread deployment [1]. Wireless technology now reaches or is capable of reaching virtually every location on the face of the earth. Hundreds of millions of people exchange information every day using laptops, personal digital assistants (PDAs), pagers, cellular phones, and other wireless communication devices. Success of outdoor and indoor wireless communication networks has led to numerous applications in sectors ranging from industries and enterprises to homes and universities. No longer bound by the harnesses of wired networks, people are able to access and share information on a global scale nearly anywhere they venture.

There are two distinct approaches of enabling wireless communication. They are infrastructure or centralised topology and ad hoc or distributed topology. The first paradigm is to let the existing cellular network infrastructure carry data as well as voice [2]. The major intricacy is the difficulty in handoff smoothly from one base station to another base station without noticeable delay or packet loss. Another snag is that networks based on the cellular structure are limited to places having cellular network infrastructure. The second approach is to use Wireless Ad hoc Networks (WANET) which consist of mobile nodes communicating over a shared wireless channel [3, 4]. Contrary to cellular networks, where the nodes communicate with a set of carefully placed basestations, there are no basestations in wireless ad hoc networks. Any two nodes are allowed to communicate directly if they are within each other’s communication range, and also nodes use multihop routing to deliver their packets to distant destinations. These infrastructureless networks have many
potential applications from Personal Area Network (PAN) to search and rescue operations.

Subsequently, the Mobile Ad hoc Networks (MANETs) have been developed to support scalability, mobility, adaptability and guarantee network performance [5]. It is an autonomous system in which mobile hosts connected by wireless links are free to move randomly and often close to humans. Such devices can communicate with another node that is immediately within their radio range (peer-to-peer communication) or one that is outside their radio range by using intermediate nodes to relay the packets from the source to the destination. Power consumption is not of prime importance in MANETs as its energy sources have high capacity and can be rejuvenated or replaced.

Technological progress enabled the spreading of embedded control in our daily life a step further. Eventually, a vision of “Ambient Intelligence” was realized, where many different devices gather and process information from many different sources to both control physical processes and to interact with human users. Therefore, a new class of network namely Wireless Sensor Network (WSN) has emerged in the last few years [6, 7]. This network consists of individual nodes that are able to interact with the environment by sensing or controlling physical parameters. The sensor nodes collaborate to fulfill their tasks by using wireless communication, as a single node is incapable of performing the task. WSNs are amenable to support a lot of different real-world applications such as environmental monitoring, surveillance, military, health and security [8-10].

1.1.1 Wireless Sensor Network Model

WSN is a particular type of ad hoc network, in which the nodes are ‘smart sensors’. These nodes are small devices equipped with advanced sensing functionalities, a small processor and a short-range wireless transceiver [11-14]. Sensor devices are deployed in strategic areas to gather data about the changes in their surroundings and report the changes to a data-sink. Also, they are expected to operate for several months to years. The data sink may be a fixed or mobile node
capable of connecting the sensor network to wireless network infrastructure or to the internet where a user can access the reported data (Fig. 1.1).

![Basic sensor network model](image)

**Fig. 1.1. Basic sensor network model**

### 1.2 GAME THEORY FOR WSN

As the demand for wireless services increases, efficient use of resources is significant. Though, reducing node energy consumption is important in ad hoc networks, it becomes very vital in WSN. In fact, the available energy is very limited in WSN due to low capacity battery. It is because of the reduced size of the sensor nodes. Despite this scarcity of energy, the network is expected to operate for a relatively longer time. As the replacing/refilling batteries are usually impossible, one of the primary design goals is to use this limited amount of energy as efficiently as possible.

Data transmission consumes the most energy among the various tasks of sensors such as sensing, computing and communication. Therefore, transmission at the optimal transmit power level is very crucial. It is due to the fact that a node will always try to transmit at high power levels just to make sure that the packets are delivered with a high success probability. Though, this increases the successful packet delivery, it proves to be counterproductive as energy is depleted faster. Also, transmitting at higher power levels increases the interference to other nodes, which in turn, will increase their power levels to combat the interference. This creates a
cascade effect, where the nodes will continue to increase their power levels in response to the increased interference. Moreover, transmission at lower power levels will compromise the quality of communication. Hence, smart power control algorithms must be employed that find the optimal transmit power level for a node for a given set of local conditions. The problem of adjusting the transmission power of the nodes in a sensor network can be solved by using game theoretic framework.

Game theory [15-17] is the theory of decision making under conditions of uncertainty and interdependence which was basically used in economics and now has been predominantly used in wireless networks. The decision makers (players) in the game are the sensors and they have to cope with limited resources that impose a conflict of interests. In an attempt to resolve this conflict, sensors make certain moves such as transmitting now or later, adapting to transmission rate or changing their transmission power to maximize their payoffs (utility).

Each player in the game maximizes some function of utility in a distributed fashion. The game settles at Nash Equilibrium (NE) if one exists. A set of strategies (in this case transmit powers) is said to be at NE if no node can gain individually by unilaterally altering its own strategy. Since, the sensors act selfishly; this equilibrium point is not necessarily the best operating point from a social point of view. Hence pricing is introduced to improve efficiency of network. It appears to be a powerful tool for achieving a more socially desirable result.

Though there are several centralised game theoretic power control approaches for cellular networks [18], these centralised algorithms suffer from major drawbacks. Typically, centralization requires substantial communication overhead within a hierarchical architecture. Hence these centralized algorithms for power control cannot be applied for sensor networks. Recently, a number of decentralized schemes for efficient power management in sensor networks have been proposed [19]. These solutions have an ad hoc flavor as they are often inspired by heuristic arguments that typically work well for very specific scenarios but lack more general theoretical support for their performance. Another approach is to provide energy efficient power management by finding the optimal transmission power level with
which a sensor node can transmit. The problem here arises due to the difficulty in characterizing the information that each sensor node has about the others. Hence, it is essential to arrive at the desired operating point in the incomplete-information scenario to enhance the lifespan of WSN.

1.3 SIGNIFICANCE OF POWER CONTROL

In a WSN, nodes share a single medium for communication. The performance of the sensor network depends on how efficiently and fairly the nodes in the network share this communication medium. A significant amount of node’s energy is spent on data transmission making communication the most energy-consuming event in WSN. One way to considerably reduce energy consumption is by applying transmission power control techniques to dynamically adjust the transmission power.

The nodes of a WSN carry extremely low energy resources and are mostly unattended after deployment. The node lifetime of WSN entirely depends on how energy can be conserved during communication. Once the battery of the nodes are exhausted, the nodes are abandoned. Therefore, it is very essential to use the power of the battery efficiently to improve the longevity of the sensor network.

Although, some exhausted nodes could be compensated using redundant neighbouring nodes, certain situations may arise leaving a part of the network completely inactive or making that part of the network inaccessible as well as isolated from the other parts. Such scenarios could be averted by avoiding unnecessary transmissions and having longer listen periods for node activities that consume the highest amount of power.

Generally, all nodes in the WSN are assumed to use the same transmission power. Increasing the transmit power provides higher Signal to Interference Noise Ratio (SINR). This offers higher data rate and intuitively enhances the network throughput. However, high transmission power will also increase the interference to other nodes. Therefore, it is required to find an optimal transmit power that achieves maximum network throughput.
The design of efficient power control is constrained by a variety of factors, such as path loss, shadowing and fading which can severely degrade the Quality of Service (QoS). Further, when mobility is introduced, the problem becomes inevitably more difficult to solve. Existing power control mechanisms for WSNs may be classified into two main categories - Passive power control (PPC) and Active power control (APC) [20]. PPC seeks to save energy by switching the radio (transceiver) interface module off when not in use. APC adjusts the transmission power according to the network operating conditions by keeping the radio interface active.

Transmission Power Control (TPC) techniques improve the performance of the network in several aspects. First, power control techniques improve the reliability of a link. Upon detecting that link reliability is below a certain threshold, the MAC protocol increases the transmission power, improving the probability of successful data transmissions [21-23]. Second, only nodes which really must share the same space will contend to access the medium, decreasing the amount of collisions in the network. This enhances network utilization, lowers latency times and reduces the probability of hidden and exposed terminals [23]. Finally, by using a higher transmission power, the physical layer can use modulation and coding schemes with a higher bit/baud ratio [24, 25], increasing the bandwidth in the presence of heavy workloads, or decreasing it to maximize energy savings.

Unlike wired channels, which are static and predictable, wireless channels are subjected to time varying impairments such as noise, interference and fading. A proven way to mitigate these effects is by employing diversity techniques. Current diversity techniques include space (antenna) diversity, frequency diversity and time diversity. Space diversity uses two or more physically separated antennas to create multiple independent fading channels. Frequency diversity takes advantage of the fact that different carrier frequencies, sufficiently spaced out, will undergo different fading characteristics over a channel. In time diversity, signals representing the same information are sent over the channel at different times under different fading conditions.
Recent breakthroughs in Digital Signal Processing (DSP) have allowed wireless communication systems to utilise both space and time diversity to address system performance needs by employing multiple antennas at transmitter and receiver to create a system with independently fading channels. A system employing more than one transmitting and receiving antenna is called MIMO system. MIMO systems have been shown to reduce the retransmission probability and lower transmission energy than that of Single Input Single Output (SISO) systems [26,27].

The transmission delay and energy are of prime importance in the process of evaluation of wireless communication systems. To ensure reliable communication over the radio channel, a system must overcome fading and interference and this can be achieved using MIMO technique. However, incorporating MIMO directly in WSNs is impractical as the node is usually limited in size. Fortunately, if multiple nodes collaborate or cooperate, a virtual antenna array can be formed to achieve spatial diversity, even though each node has only one antenna in WSN. Moreover, if 8 nodes near the sender and receiver cooperate to form sending and receiving group, the amount of channel estimation at the receiver in WSN can be reduced from 64 to 8.

MIMO can be easily realised through Space Time Coding (STC) which transmits multiple copies of data stream across number of antennas [28]. The design of these codes takes into account a trade-off between decoder complexity at receiver, maximising the information rate and minimising decoding errors. Copies of the signal received through multiple antennas are combined in an optimal way to extract information from each of them. This ensures optimal reception of data in a potentially difficult environment with noise, interference and fading associated with wireless scenario.

In addition, the clustered architecture can simplify network management and routing with large number of sensor nodes. This can greatly reduce the energy consumption and transmission delay of sensor nodes without compromising the quality of the network.
Since, the sensors are miniature battery powered devices, it is essential to conserve the battery resources to enhance the lifespan of WSN. This improvement in lifetime can be achieved through efficient power control techniques. Game theory is one of the promising technique to be applied for power control in WSN. The centralised power control algorithms for cellular network cannot be directly applied to WSN because of the communication overhead incurred. Hence, there arise a need for designing efficient decentralised game theoretic power control techniques for WSN to improve the lifetime of the network.

1.4 SCOPE OF THE WORK

Energy saving is the most important issue in research and development of WSN. Sensor networks have their limitations on energy due to interference, radio irregularity and fading. The search to accomplish this requirement is to consider power control mechanism with ECC, MIMO, appropriate node deployment schemes and AMC, which can reduce the power consumption of the nodes in the network.

Initially, iterative power control algorithms were proposed for cellular networks. These centralised algorithms investigate to find the power vector for all the nodes that minimizes the total power with good convergence. But, these centralised algorithms cannot be directly applied to sensor networks.

Subsequently, MIMO schemes have been used to coordinate the actions of distributed sensors to combat fading and radio channel interference of wireless medium. A drawback of MIMO techniques is that they require complex transceiver circuitry and large amount of signal processing power resulting in large power consumptions at the circuit level. This fact has so far precluded the application of MIMO techniques to wireless sensor networks consisting of battery-operated sensor nodes. In WSN, the MIMO is realised virtually with the cooperative sending and receiving groups. Diversity gain is achieved through space time code to reduce channel fading, interference to improve the performance of wireless communication systems.
Another approach to combat fading is to use adaptive modulation. It refers to the automatic modulation adjustment that a WSN can make to prevent weather-related fading from causing communication on the link to be disrupted. The radio system automatically changes modulation depending upon the prevailing channel condition. Since communication signals are modulated, varying the modulation also varies the amount of bits that are transferred per signal, thereby enabling higher throughputs and better spectral efficiencies. As a higher modulation technique is used, a better Signal-to-Noise Ratio (SNRs) is needed to overcome interference and maintain a tolerable Bit Error Rate (BER) level.

The game theory has been used to study various aspects of ad hoc and sensor networks. However, attention has not been focused on the power control problem in WSN using game theoretic approach. The use of Reed Solomon (RS) and Multivariate Interpolate Decoding RS (MIDRS) codes in the power control game has not yet been analysed. Also, a proper node deployment scheme that can extend the lifetime of WSNs by minimizing energy consumption has not been attempted. Furthermore, space time codes with game approach are yet to be explored for enhancing the performance of VMIMO based WSN. A power control game for AMC considering the energy of the nodes has not been fully analysed in WSN.

Hence, in the present work, an attempt is made to develop game theoretic framework that helps the nodes to decide on the optimal power levels for a specified objective given by the utility function. The power control in WSNs is done with efficient power control games using ECC, proper node deployment schemes, VMIMO schemes using cooperative Space Time Block Code (STBC) schemes and AMC.

1.5 OBJECTIVE OF THE WORK

An attempt is made in the present work to enhance the network lifetime of WSN through game theoretic approach by employing efficient ECC technique, deployment schemes, MIMO and AMC. The objectives set in the present work are as follows.
To develop a game theoretic framework for power control using error control coding and evaluate the performance metrics such as utility, power efficiency and energy consumption of sensor network.

To propound appropriate node deployment schemes and investigate the network performance using game approach considering residual energy check to achieve minimum energy consumption and enhanced network lifetime.

To design a VMIMO scheme based on STBC using game theoretic approach to accomplish energy savings and to enhance the utility.

To incorporate adaptive modulation and coding and analyse the system performance in terms of utility and energy consumption to prolong the network lifetime.

1.6 ORGANISATION OF THE THESIS

The Chapter 1 provides an overview on WSN system. The need, scope, the principal objectives pertaining to the present work and the organisation of the thesis are presented in this chapter.

Extensive literature associated to the power control approaches for WSN system and game theory has been critically reviewed and is presented in Chapter 2. Summary of the review of literature is also furnished at the end of the chapter.

Chapter 3 narrates an energy efficient power control algorithm using ECC with game theoretic approach in WSN. The utility function devised mathematically for the proposed system is also presented. A detailed discussion on power control with the aid of simulation results for the system employing RS and MIDRS codes are incorporated in this chapter.

Chapter 4 deals with the analysis of various deployment schemes for WSN. A detailed discussion on the simulation results and the performance is succinctly offered for the system. Utility and energy consumption employing game theoretic approach with and without energy check are also incorporated.
Cooperative MIMO system model using STBC with game approach is described in Chapter 5. The game theoretic approach for power control in VMIMO WSN using MIDRS code is also presented. The mathematical model to evaluate the performance of the system is cogently presented. Further, the simulation results in terms of utility, power efficiency, energy and lifetime analysis of both STBC and uncoded scheme for different diversity orders are also furnished.

Chapter 6 deals with the adaptive modulation and coding for energy efficient communication in WSN. The mathematical model representing the proposed system is devised and presented. Using this approach the energy efficiency to maximise the network lifetime is studied and quantified with results.

Chapter 7 concludes the thesis by emphasizing the major implications of the study. A summary of research contribution and the scope for the future studies are also furnished in this chapter.