POWER CONTROL IN WIRELESS NETWORKS : A SURVEY

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ABSTRACT

Wireless ad hoc network is a collection of wireless nodes that can dynamically organize itself into an arbitrary and temporary topology to form a network. This does not necessarily use any pre-existing infrastructure. These characteristics make ad hoc networks well suited for military activities, emergency operations and disaster management. Power optimization techniques are becoming increasingly important in wireless system design since the battery technology has not kept up with the demand of the mobile devices. Power control in wireless networks largely improves the capacity of the network and energy savings. The energy saving has been found to be improved by utilizing more number of intermediate hops between base source and destination. This paper aims to provide a survey of some existing approaches to transmission power control for wireless networks.

Keywords: Power Control, Wireless networks, Capacity Improvement

I. INTRODUCTION

Ad Hoc wireless networks are infrastructure-free wireless networks consisting of nodes that communicate with each other across wireless links directly or through possibly intermediate nodes. The network capacity is the sum of the throughput provided to end users in a network. This value is one of the fundamental characteristics of a network, which is a function of factors like nodal density and distribution, mobility, traffic pattern, size of the network, transmission power and bandwidth constraints, and antenna directionality. The power control optimization is described by optimization variables, like objective functions and constraint sets. Some examples of transmit power control problems have been described in wireless ad hoc networks [1-3] and in wireless cellular networks [4-7].

The transmit power control problems for wireless mesh networks are classified according to the solution techniques.

The classifications are Mathematical Programming [6,9-11], Branch and Bound [12,13], Protocol heuristics [2,3,14-18], Simulated annealing [30], Game theory [19-21], predictive methods [8,7,23], Kalman methods [24,25] and cross-layer approaches [9,22].

This paper surveys a number of contributions that have collectively developed a metric for the analysis of decentralized wireless network known as transmission capacity.

The main objective of this paper is to review the main approaches for transmission power control that have been proposed in the literature. Section II provides some reviews on algorithms used for power control based on Mathematical Programming Techniques. Section III discusses algorithms based on game theoretical techniques – both cooperative and non-cooperative game theory approaches. Finally, the conclusion is given in Section IV.

II. ALGORITHMS BASED ON MATHEMATICAL PROGRAMMING TECHNIQUES

In wireless cellular or Ad Hoc networks, interference limits the quality of service (QoS) [10]. The power control problem was considered as a nonlinear optimization with the objective of maximizing the total system throughput and was subject to various QoS constraints such as data rate, delay,outage probability and Bit error rate.

One of the methods used in wireless networks to compensate fast fading and time varying characteristics of wireless channel is closed-loop power control [54,55]. One of the most common approaches to closed-loop power control in wireless networks is SIR balancing, which is also called power balancing.

Yet another class of algorithms seeks to solve a static optimization problem. The distributed constrained power control algorithm is found to maximize the minimum attained user SIR subject to maximum power constraints [56,57].

Chiang et al [10] have shown that the Geometric Programming technique turns the constrained optimization of power control into convex optimization, in spite of the non-convexity involved. There have also been efforts to solve the Signal-to-Interference plus noise ratio (SINR or SIR) based power optimization problems. Certain algorithms try to minimize total power consumption over a discrete set of power levels [26], while certain algorithms try to minimize the outage probability of the SIR. [12,27].The relationship between link scheduling and power control have been examined in order to maximize the throughput [28]. The maximum throughput link scheduling is considered as a mixed integer linear programming problem and the power control uses directional antennas [29].

Montemanni et al., [31] have presented a minimum power symmetric connectivity problem in wireless networks. It is based on the broadcasting capability of the wireless networks, so that several nodes can be reached with a single transmission. Branch and cut algorithms have also been used. [11,30,31,32]

Extensive studies have also been carried out for power optimization based on Integer Linear Programming. [4,33,12,27,29]. Power and rate control outage based under multiple access interference and heterogeneous traffic sources have been proposed by [12,27]. The authors formulated the total rate maximization problem by a base receiver station for all nodes. The outer and inner loop power control algorithms have been adopted. The outer loop power control is responsible for setting the target SINR at the receiver input and the inner loop control compensates channel variations induced by fast fading phenomena.

Capone and Carello [34] have addressed both power control and rate adaptation. The objective function was fixed as minimizing the number of used time slots, subject to transmission power constraints. A column generation approach was used to solve the minimal power variables. Numerical results have shown that the column generation approach can solve small size instances, while the whole approach becomes slow for bigger problems. This method assumed a centralized arbiter to maintain and distribute time slots across the system and thus overhead costs that exacerbate retransmission problems.

For a generalized SIR regime, Chiang et.al [9] have described a distributed power control algorithm that combines existing transmission control protocols to increase end-to-end throughput and energy efficiency of the network. A nonlinear constrained utility maximization has been formulated. The convergence of the coupled algorithm to the global optimum of the joint power control and congestion control has been proved, for both synchronized and asynchronous implementations. The rate of convergence was found to be geometric and that a desirable modularity between the transport and physical layers can be maintained. Analytic and simulation results have shown the robustness of the algorithm to channel-outage and to path-loss estimation errors. However, the algorithm trades-off implementation simplicity for performance optimality.

Chiang et al [10] have shown that with high SIR, the nonlinear and non-convex optimization problems can be transformed into convex optimization problems in the form of geometric programming. In the case of medium and low SIR, some of these constrained nonlinear optimizations of power control cannot be turned into tractable convex formulations. These techniques for power control, together with their implications to admission control and pricing in wireless networks, are illustrated through several numerical examples. The GP method is found to be effective to certain applications but requires high SIR channels [35].

III. ALGORITHMS BASED ON GAME-THEORETICAL TECHNIQUES

In wireless communication systems, the transmission power of each user contributes to the interference seen by the other users [36]. Since the availability of battery power is limited at each node and the demand by each user is unlimited, there is a need for effective and efficient power control strategies. The strategies may be designed to achieve user oriented quality of service (QoS) or system capacity objectives or both [37].

Game-theoretic analysis of Ad Hoc networks have been assessed in terms of power control and waveform adaptation, medium access control, routing decisions, and node participations.[19]. The medium access control problem, where many users contend for access to a shared medium, lends itself naturally to a game theoretic formulation. In these approaches, users try to obtain an unfair share of access to the channel in order to maximize utility. This however decreases the ability of other users to access the channel.

Game theory is broadly categorized as cooperative game and non-cooperative game [26]. Several publications based on the cooperative game can be found in [26, 38-41] and those for non-cooperative game are found in [42].

Cooperative Game Based Algorithms:

One of the earliest applications of game theory to a medium access control problem is available in [49] and [50]. However, the game considered is cooperative in nature and does not consider contention between selfish nodes themselves. Mackenzie and Wicker pose the slotted Aloha medium access control protocol itself as a game between users contending for the channel in [51], [52], and [53].

A utility-based network assisted power control has been proposed [38]. The power control algorithm was implemented through SIR balancing with the assistance of the network that broadcasts the common SIR target for all users. This algorithm requires coordination by the network, which has to inform terminals of the best target SIR for current conditions. The utility levels achieved with this algorithm are comparable to those achieved with a non-cooperative power control game with pricing [43]. But flooding problems have been found to be caused by network broadcasts [16]. The main drawback is that coordination is required by the network through broadcasts and therefore there is a lack of fault-resilience.

Jean and Jabbari [41] presented a game-theoretic delay-sensitive multi-rate power control for CDMA wireless networks with variable path-loss. A stochastic game-theory has been applied and it models the dynamism of the cellular uplink power-control problem. The stationary Nash equilibrium is evaluated as a function of buffer level variation in time and allows for multi-rate transmission in evolving channel conditions. The stochastic game equilibrium calculated compares very favorably to traditional single-agent and often approaches the performance of centralized optimization, in both static path-loss and dynamic shadowing path-loss environments.

Huang et al, [39] have studied the performance of a distributed and asynchronous power control scheme for a spread spectrum wireless Ad Hoc network. The network users exchange prices that reflect their loss in utility due to perceived interference. The pricing algorithm exhibited rapid convergence to the unique optimal power allocation.

In another contribution, Huang *et al.,* [40] have considered a distributed power control scheme in a spread spectrum wireless ad hoc network. Each user announces a price that reflects his current interference level. The node users have been assumed to and are found to voluntarily cooperate with each other by the exchange of interference information. Given these prices, the authors presented. An asynchronous distributed algorithm for updating power levels was presented and the condition under which this algorithm converges to an optimal power allocation was described.

Altman *et al.,* [26], the authors have considered an uplink power control problem in which each node wishes to maximize its throughput but has a constraint on the average power A finite number of power levels are assumed to be available to each wireless node. The node selects a particular power level, based on its channel state. Two cases are considered: full state information and local state information. In both, the both cooperative and non-cooperative power control has been proposed. However, cellular radio system has been assumed even in the case of local state information and thus the method lacks scalable attributes of multi-hop WBMNs.

Non Cooperative Game Based Algorithms:

The power control problem in wireless networks has been formulated as a non-cooperative game[37], in which users choose to trade off between SIR error and transmission power usage. The SIR error is minimized at the cost of high of the transmission power usage. A distributed power control strategy has been used and is based on the Newton iterations having third-order rather than quadratic convergence. Simulation uses the CMDA cell model and the results indicated that the use of Newton iterations to accelerate the convergence of the static Nash power control algorithm significantly decreased the number of iterations required for convergence.

Meshkati et al.,[42] has proposed a game-theoretic approach to energy-efficient power control in multicarrier CDMA systems. In multi-carrier direct-sequence CDMA, the data stream for each user is divided into a multiple parallel streams. Each stream is first spread using a spreading sequence and then transmitted on a carrier. The benefits of orthogonal frequency-division multiplexing (OFDM) have been combined with those of CDMA for the next-generation high data-rate wireless systems. In [42], power control problem has been formulated as a non-cooperative game in which each user decides how much power to transmit over each carrier to maximize its own utility. The utility function considered measures the number of reliable bits transmitted over all the carriers per joule of energy consumed. The authors have proposed an iterative and distributed algorithm for reaching the equilibrium. The results indicate significant improvement in the total utility achieved at equilibrium compared with a single-carrier system and also to a multicarrier system in which each user maximizes its utility over each carrier independently.

Liang and Dandekar[44] have proposed a game-theoretic power management in multi-input multi-output (MIMO) Ad Hoc networks. The power allocation at each user is built into a non-cooperative game where an identified utility function is maximized.

A few users have very low data transmission rates even when the transmit powers are high since the channel conditions are poor. Co-channel interference was reduced and energy-efficiency was improved by shutting down the link users in this method. This game-theoretic approach with the link user shut-down mechanism allows the MIMO ad hoc network to achieve the high energy and the high system capacity.

In [21] a stochastic learning solution for distributed discrete power control game in wireless data networks has been proposed. It was found that a simple discretization of the continuous transmitter power level does not guarantee convergence and uniqueness. Therefore, two probabilistic power adaptation algorithms were proposed and both theoretical properties and numerical behavior were analyzed.

Xing and Chandramouli [21] have approximated the discrete power control iterations by an equivalent ordinary differential equation and proved that the proposed stochastic learning power control algorithm converges to a stable Nash equilibrium.

In [45] a cognitive network approach has been presented with the objectives of power and spectrum management. A two phased non-cooperative game was assumed. A topology was constructed to minimize the maximum transmission power. The properties of potential game theory have been used to ensure the existence of and convergence to a desirable Nash Equilibrium.

Closas *et al.,* [65] use a non-cooperative game theory to design a fully distributed network topology control algorithm using optimal transmit adjustment. The authors have shown that for a relatively low node density, the probability that the proposed algorithm leads to a connected network is close to one.

Huang *et al.,* [47] have proposed two auction mechanisms, the SINR auction and the power auction, that determine relay selection and relay power allocation in a distributed fashion. Simulation results show that the power auction achieves the efficient allocation by maximizing the total rate increase for a single relay network case. SINR auction was found to flexible in trading off fairness and efficiency. The distributed best response bid updates globally converged to the unique Nash Equilibrium in a completely asynchronous manner for both considerations. Same results were obtained considering generalized networks with multiple relays.

In [48], a similar approach has been used and non-iterative power control algorithms with mutually interfering users and a common target SINR has been considered. The channel quality of the intended receiver is known by each transmitter. The transmitters have no knowledge of interference from other transmitters. The authors have considered fractional control policies and a spatially distributed network, representing either a wireless Ad Hoc network or unlicensed spectrum usage by many nodes. It was found that the required latency may not be available or convergence times may be too long relative to packet duration in the case of iterative power controls.

Vallam et.al [58] have studied the problem of non-cooperative channel assignment in multi-channel multi-radio networks with multiple collision domains. A new fairness measure in multiple collision domains has been proposed and fair equilibrium conditions are derived. The authors have more significant contribution in system fairness and uses an advanced learning algorithm in the system convergence.

IV. CONCLUSION

The algorithms for transmission power control problems for the wireless networks have been extensively addressed in the literature. Mathematical programming techniques such as Geometric Programming, Linear programming provide a generalized tool for the power control problems. Depending on the complexity and the dimension of the problem, feasible optimal solutions are feasible. Decentralized power control problems are useful in formulating non-cooperative games, but it maybe difficult to find the Nash equilibrium in a wireless system. Co-operative games maybe difficult in real life and the objective function may, therefore be formulated considering the benefits of the two types of games.

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