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Wireless Mesh Networks Path Planning, Power Control and Optimal Solutions

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ABSTRACT
Wireless mesh networks are considerd as a potential attractive alternative to provide Broadband acces to users. In this paper we address the following two questions: (i) Given a set of nodes with arbitrary locations, and a set of data rows, what is the max-min achievable throughput? And (ii) How should the network be configured to achieve the optimum? Given a set of nodes with arbitrary locations, and a set of data rows specified as source-destination pairs, what is the maximum achievable throughput, under certain constraints on the radio parameters in particular, on transmit power. How should the network be configured to achieve this maximum? Specifically, by configuration, we mean the complete choice of the set of links (i.e., topology), the routes, link schedules, and transmit powers and modulation schemes for each link.
Keywords- Greedy pricing, optimal solutions, Path planning, Power control, Throughput,

I. INTRODUCTION

Characterizing the capacity of a wireless network has turned out to be a difficult problem of communication over a wireless medium. Beginning with wireless mesh networks a popular approach has been to characterize the asymptotic scaling of capacity in the number of nodes. By asking for bounds only in an order sense, it has been possible to derive the trend of capacity scaling, even in the information theoretic sense. However, although the knowledge of a capacity scaling law is quite valuable, it lends no insights into actual numbers for network capacity based on current technologies, or into the impact of macroscopic parameters such as transmits power budget and the availability of modulation schemes, on the network capacity. There has also been some work on optimally operating a wireless network; for example, in a routing and power control policy to stabilize the network is devised and in a power transmission strategy to minimize the power cost subject to average rate constraint is found. Owing to their focus on the algorithmic perspective, these works also do not shed any light into the network capacity, and an optimal configuration of a given wireless network to achieve it. This is the problem we seek to address in this thesis.

1.2 Motivation

We consider the above questions from a networking standpoint, and pose them as an optimization problem to determine jointly optimal row routes, link activation schedules and physical layer parameters. We obtain some interesting insights into the interplay of the achievable throughput, routing and transmit power and modulation schemes. Determining the achievable throughput is computationally hard in general, however, using a smart technique we obtain numerical results for different scenarios of interest. We believe that our optimization based framework can also be used as a tool, for planning and capacity provisioning of wireless networks.

II. WIRELESS MESH NETWORKS

In this work, our notion of the maximum throughput is the max-min low rate, i.e., the maximum of the minimum end to end row throughputs that can be achieved in the network. This is an appropriate notion of capacity from a networking perspective since it may represent the aggregate bandwidth demands of subscriber stations in an IEEE 802.16-like access network, or the sampling rate at which sensors produce information about their environment, in a sensor network. We assume point-to-point links which can operate in accordance with their perceived signal-to-interference-and-noise ratio (SINR). We also assume that transmissions are co-ordinate (possibly, though not necessarily, by a central controller) so as to be conflict-free through activation schedules.

Fig 2.1. A WMN with uplink and downlink flows

Thus, our bounds reject the intrinsic limits posed by the underlying conflict structure of parallel transmissions, as dictated by the SINR calculations. The second question we answer is the following.

We assume that the wireless nodes have an arbitrary set of transmit power levels, and an arbitrary set of modulation and coding strategies. All wireless links are considered to be operated at some required bit-error-rate (BER). A transmission on a wireless link is said to succeed, if the SINR perceived by the link remains greater than an SINR threshold which depends on the transmit power, modulation and coding, and the requisite BER. We show that this requirement results into a conflict set for each wireless link. For a given link, the corresponding conflict set is a collection of subsets of links, such that at least one link from each subset cannot be activated simultaneously with the given link (in the sense of satisfying the BER requirement).

To resolve Q1 and Q2 we take a constructive approach, i.e., we explicitly construct a network that has the maximum throughput. Since the problem is to construct a throughput optimal network, the idea is to pose it as a problem of optimal resource allocation and routing on a .dummy network. Specified by the complete graph on given wireless nodes.

We discuss two static optimization formulations for this problem. They are complementary in the sense that one throws light on the routing perspective while the other on the scheduling perspective. It can be shown that determining the maximum throughput is a computationally hard problem in general. However, using a smart enumerative technique, for specific instances of the problem computations can be greatly reduced. We provide results for different scenarios of interest such as a sensor network on a grid, and a mesh of nodes deployed in hexagonal cells.

A static optimization setting similar to ours has been discussed in [3], [4]. In [4], the authors focus on a low SINR regime with the link capacities being linear functions of the perceived SINR. In our work, we consider modulation and coding schemes as determining the link capacities, rather than approximations of the Shannon capacity function. In [3], the authors use a conflict graph formulation to model the schedulability relationships between the wireless links. Our results are based on a more general conflict set formulation, and while they certainly support those in [3], they further provide important insights into the impact of macroscopic parameters such as transmit power budget and availability of modulation schemes, on the throughput performance. Further, the upper bounds on throughput derived in [3] are rather loose and consider only the cliques formed by singleton conflict set members. Under these assumptions, the problem of resource allocation and routing can be cast simply as an optimal routing problem. The idea is to replace a link say, between nodes i and j, by multiple .artificial links. Each one corresponding to one combination of transmits power levels and modulation coding schemes available at i . Thus, optimal selection of power and modulation is translated into optimal selection of links. Some basic notation is in order. N denotes the number of given static wireless nodes; their set is denoted by N. L denotes the set of all possible links among these nodes; L includes all artificial links as discussed above. Cardinality of L is denoted by L. Links are assumed to be directed; l 2 L is also represented as (lo; ld), where lo and ld denote the originating and the destination nodes resp. LOi (resp. LIi) denotes the set of links outgoing from node i (resp. incoming to i). Let Pl denote the transmission power on link l and zl the corresponding modulation-coding scheme.

The characteristics of WMNs are explained as follows:

- Multi-hop wireless network. An objective to develop WMNs is to extend the coverage range of current wireless networks without sacrificing the channel capacity. Another objective is to provide non-line-of-sight (NLOS) connectivity among the users without direct line-of-sight (LOS) links. To meet these requirements, the mesh-style multi-hopping is indispensable, which achieves higher throughput without sacrificing effective radio range via shorter link distances, less interference between the nodes, and more efficient frequency re-use.
- Support for ad hoc networking, and capability of self-forming, self-healing, and self-organization. WMNs enhance network performance, because of flexible network architecture, easy deployment and configuration, fault tolerance, and mesh connectivity, i.e., multipoint-to-multipoint communications. Due to these features, WMNs have low upfront investment requirement, and the network can grow gradually as needed.
- Mobility dependence on the type of mesh nodes. Mesh routers usually have minimal mobility, while mesh clients can be stationary or mobile nodes.

- Multiple types of network access. In WMNs, both backhaul access to the Internet and peer to peer (P2P) communications are supported. In addition, the integration of WMNs with other wireless networks and providing services to end-users of these networks can be accomplished through WMNs.
- Dependence of power-consumption constraints on the type of mesh nodes. Mesh routers usually do not have strict constraints on power consumption. However, mesh clients may require power efficient protocols. Mobility. Since ad hoc networks provide routing using the end-user devices, the network topology and connectivity depend on the movement of users. This imposes additional challenges on routing protocols as well as on network configuration and deployment.

2.2. Analysis on min-hop network:

Now let us look at Figure 3 and Figure 4 which depicts the optimal routing under different choices of transmits power and modulation and coding scheme. The range of a sensor node in the configuration in Figure 3 is 16 m which is twice the grid side, and in Figure 4 it is 12:7 m which is more than the grid diagonal. Note that in both the cases, the optimal routes are not minimum hop, for all the nodes. Within the region indicated by the dotted line in both the figures, the nodes use minimum hop paths, although in Figure 3 some sensors split their data along multiple paths not all of which are minimum hop. Also, observe that the nodes along the diagonal, beyond the dotted line, route their data along the periphery of the network. This is an illustration of what may be termed interference-avoiding routing.

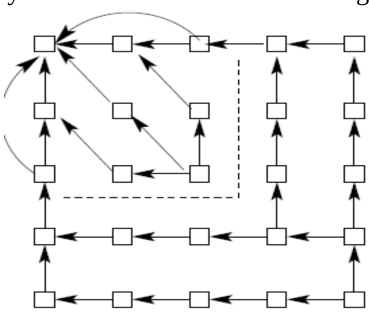


Fig 2.1 Mini-hop network

2.2.2 Analysis on multi-hop network:

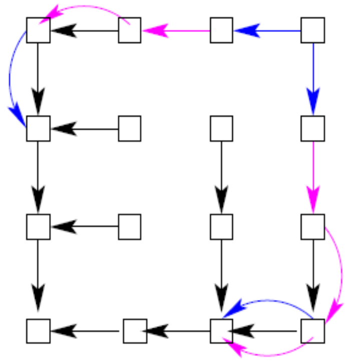


Fig 2.2 Multi-hop network

This example is identical. However, there are only two data rows (indicated as red-straight edges and blue-curved edges). The red row originates at the bottom left corner node, and is destined to the red node adjacent to the top right corner. Likewise, for the blue row.

The optimal routes which achieve the max-min throughput for the two data rows are indicated by the red and blue links in Figure 5. The dotted links carry less than 15% of the total traffic, and more than 80% of the total traffic is carried along the periphery over the solid links. In this case, the range of each node is 11:3 m which is equal to the grid diagonal. However, the routing uses only two diagonal links, and is far from minimum hop. Although some data is routed along common paths and links, the bulk of the data is routed so that the rows .avoid each other.

2.3 The multi-hop advantage:

In a mesh network with **diverging** flows, the maximum achievable throughput can be obtained by using a much lower transmit power at the gateway using multi hop communication than with single-hop communication.

III. IMPLEMENTATION

The thesis model the network n of nodes (the mesh routers and the gate way) and a set l of directed links with mod N=n and mod l=l each node has a location (xi,yi) we denote by l the set of links incident to a node i.a link il is identified not only by its origin destination pair but also its physical parameters which are defined .a f denotes set of flows and let mod f=f a flow f is identified not only by its origin destination pair (fs,fd) and has a rate lambda.

We present models for the scheduling, rate adaptation, and power control problem whose solution can be used to configure the network. Note that, in all cases, we restrict ourselves to conflict-free scheduling Each link is I belongs l identified by four physical parameters O(l),d(l) the origin and the destination nodes of l. a link is sometimes denoted (I ,j)when ever Pt: transmit power, Ct: the link rate per second.

$$\mathrm{SNR}_l = \frac{G_l P_l}{N_0} \geq \beta(c_l)$$

3.1 Additive interference model:

It's used to extends the physical interference model.

$$\gamma_l = \frac{G_l P_l}{N_0 + \sum_{l' \in s: l' \neq l} G_{l'l} P_{l'}} \geq \beta(c_l) \quad \forall l \in s.$$

The maximum throughput attained when

$$\begin{array}{llll} & \max_{\lambda, \mathbf{x}, \boldsymbol{\alpha}} & \lambda & \\ (\mu_i^f) & & A^f \mathbf{x}^f \geq \lambda \mathbf{d}^f & \forall f \in \mathcal{F} \\ (\nu_l) & c_l \sum_{s \in \mathcal{I}} q_{l,s} \alpha_s \geq \sum_{f \in \mathcal{F}} x_l^f & & \forall l \in \mathcal{L} \\ (\zeta) & & \sum_{s \in \mathcal{I}} \alpha_s \leq 1 & \\ & & \mathbf{x}, \boldsymbol{\alpha} \geq \mathbf{0} & \end{array}$$

In this formulation, we have and. The maximization is explicitly taken with respect to the maximum flow and link load allocation We call this problem JP-Primal. It is a standard but very large linear program (LP) and its difficulty lies in the computation of the incidence matrix which grows exponentially with the problem size.
The maximum throughput is attained by

$$\begin{array}{ll} \max \lambda & \\ \sum_{f \in F} \lambda_f \left(\sum_{r \in \mathcal{R}_f^l} \phi_f^r \right) \leq c_l(\alpha) & l = 1, \ldots, L \\ \sum_{r \in \mathcal{R}_f} \phi_f^r = 1, \phi_f^r \geq 0 & f = 1, \ldots, M \\ \lambda \leq \lambda_f & f = 1, \ldots, M \\ \lambda \geq 0, \alpha \in \mathcal{A} & \end{array}$$

Perceptive behavior is a class of mechanisms that empowers wireless devices to exchange information during normal packet delivery and to coordinate and communicate with other nearby devices, even though some of these devices may be outside of direct communication range.

3.2 Reactive routing:

We design, develop and test several components of reactive routing in wireless multi-hop networks. Our research leads to significant improvement and has made deployment of ad hoc networks more feasible. Our initial focus was development of an Ad hoc On-demand Distance Vector (AODV) routing daemon. Our implementation is known as AODV-UCSB. While developing the implementation, we identified several ambiguities and errors in the protocol specification. Our insight significantly influenced the contents and structure of the AODV Experimental RFC.

IV. TOOLS FOR EXACT SOLUTIONS

This means solving a very large LP with a coefficient matrix that grows exponentially with the size of the network. We now present two efficient algorithms that solve JP exactly. we construct the matrix using an efficient enumeration of the ISets.

4.1 Solution by the simplex algorithm:

We propose here an efficient algorithm that constructs all possible ISets but no more. The complexity of this method is only as opposed to in [2], where is the maximum ISet size and typically .

We describe it using a recursive depth-first algorithm, but we have also implemented an iterative breadth-first version. While the recursive form is simpler to program and is well suited for enumerating all ISets, the iterative form is better suited for enumerating only the *maximal* ISets. The algorithm is based on the following proposition that is trivial to prove.

Proposition 1:
If is an independent set, then any subset of is also an independent set.

Algorithm *Prune The Candidate List*

1. define prune(s, Λ)
2. $\Lambda' \leftarrow \emptyset$
3. $\bar{l} \leftarrow \max_{l \in s} l$
4. **for** $l \in \Lambda$
5. **if** $l > \bar{l}$ and $\{l\} \cup s$ is an ISet
6. $\Lambda' \leftarrow \Lambda' \cup \{l\}$
7. **return** Λ'

The algorithm builds ISets of increasing sizes and stops when this is no longer possible. This is done using an enumeration tree as follows. The root node is at depth 0. A node at depth contains an ISet of links and a list of links that are candidate for addition to this ISet. We assume that is implemented as an ordered data structure indexed by increasing link number. Consequently, means that appears later than in and returns the link whose index number is the largest in .We define two functions. The first one is prune , which returns a reduced candidate list of links constructed as described in Fig. 1. The condition on line 5 for adding a link to an ISet has two parts. The first is used to avoid enumerating ISets more than once, and the second tests the set against the appropriate interference model defined in Section III-B.

The first condition is due to the fact that the ISets are built in a precise order. At a given depth in the tree, the tree nodes contain ISets of links and are built left to right with the link numbers in an increasing lexicographic order. Suppose that and that. Since there is already a node to the left of the current node containing the ISet , there is no need to add to .The other function akeSons is a simple recursive procedure that builds all the children of a node for a given candidate list . It should be clear that a child of is an ISet that differs from by one link. The set of ISets is accumulated at each node until the whole collection is built up. Finally, the algorithm is initialized with the root node empty, and the first candidate list is the set of all links.

4.2 Solution by column generation:

Even with the most efficient enumeration technique, the approach of Section IV-A will eventually become infeasible due to the large size of set . On the other hand, we know that only a few ISets will be active in the optimal solution by the following proposition.

Proposition 2:

The number of nonzero elements of , i.e.,the number of ISets that are effectively used, in a basic solution of JP-Primal is at most . This follows directly from Carathéodory's theorem. This suggests that we use column generation to solve the problem, thus voiding the explicit generations of . If we write the constraints in standard matrix form, the column corresponding to constraints (4) and some variable has the form . These are used for pricing the ISets as follows.

1.3 Exact Pricing:

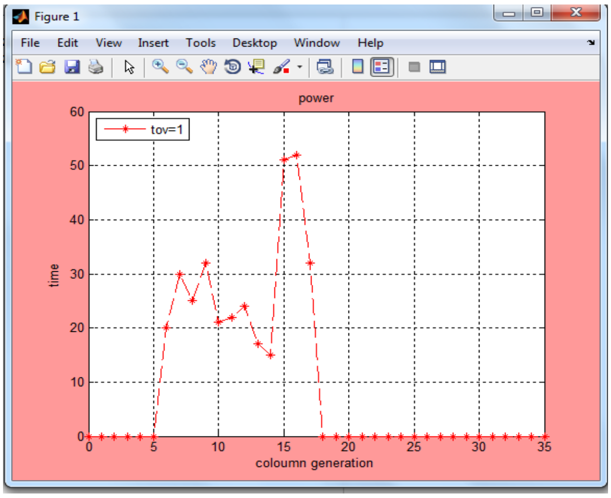
Column generation is basically the revised simplex algorithm with a particular pricing echnique. The technique uses only a subset of columns , which is called the Restricted Master Problem (RMP). At a given iteration, we have, for the RMP, a basic feasible solution, and as well as the current estimate of the dual variables , , and The first step of the next simplex iteration is to price the offbasis columns. The reduced cost of an off-basis column is given by the standard formula since the cost coefficient of the off-basis variable in the objective function is zero. When the objective is to maximize, the standard pivoting rule of the simplex is to choose the column with the largest reduced cost. The stopping rule is also simple: If there is no off-basis column with a strictly positive reduced cost, the current solution is optimal. This means that the pricing requires the solution of the following *Maximum Weight ISet* (MWIS) problem with as the link weights subject to constraints (1) and (2). It can be easily shown that it is an NP-hard problem. If we want an optimal solution, we must make sure that there is no off-basis column with a strictly positive reduced cost at the last simplex iteration. This in turn means that we have to solve the MWISpricing subproblem to optimality. It will then become very difficult to compute large networks by a straightforward column-generation technique. This is why we propose another method called *greedy pricing*, which has been proven to be very fast at delivering exact solutions.

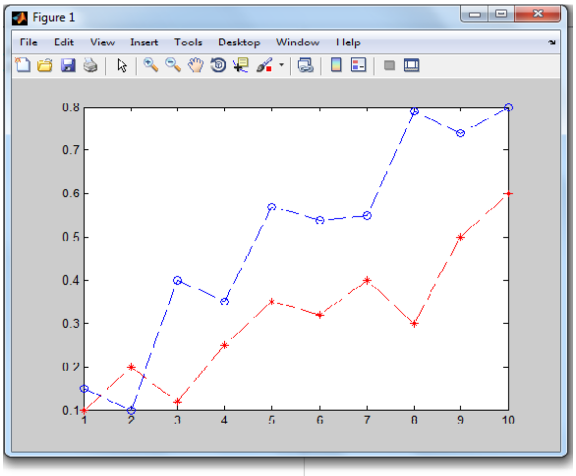
1.4 Greedy Pricing:

We can reduce the amount of computation if we use a greedy pricing rule at each iteration. This is based on the fact that choosing *any* column with a positive reduced cost may potentially produce a new solution with a higher value of the objective. We can also speed up the calculation by solving the pricing subproblem over a set of links with positive reduced costs only. The reason is that if there exists a solution to the MWIS problem where some links with zero reduced costs appear in the solution, then there is an optimal solution made up of only the links with strictly positive reduced costs. This follows from *Proposition 1*.

The algorithm to find a new column for the RMP with a positive reduced cost uses two functions, denoted as greedy and enuoracle. They take a link set as the input and return an ISet with a positive reduced cost, if such a set exists, or an empty set. In a basic implementation of greedy, the algorithm simply orders the links in decreasing weights.

V. RESULTS





VI. FUTURE SCOPE

Considering the scheduling routing and rate of adaption maximum throughput is attained considering out chip (channel) signals. The wireless mesh networks of minimum interference and maximum throughput is to be achieved .

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