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Hongxing Li

I. Optimization Problem

Continued with the topic in last report, I am exploring the minimum-latency or minimum-power-consumption link scheduling in arbitrary directed acyclic networks with order or precedence constraints.

In order to combine the "latency" and "power consumption" minimization into a more general problem, I define an utility function as

$$U = T^a \|P\|_1^b$$

where, T is represents the scheduling latency and $\|P\|_1$ is the total power consumption. $a \in [0,1]$ and $b \in [0,1]$ are weights for T and $\|P\|_1$ respectively. Thus we have

$$U = \begin{cases} T & \text{if } a = 1 \text{ and } b = 0 \\ \|P\|_1 & \text{if } a = 0 \text{ and } b = 1 \\ T \cdot \|P\|_1 & \text{if } a = 1 \text{ and } b = 1 \end{cases}$$

Given with graph $G(V, E)$, V is the node set with n arbitrarily distributed nodes and E is the link set which is represented as a matrix.

$$E(i,j) = \begin{cases} 1 & \text{if } e_{ij} \in G \\ 0 & \text{Otherwise} \end{cases}$$

For each link $e_{ij} \in E$, a sub-set of E, which is E_{ij} and also the subtree of node i, should be scheduled before e_{ij}. We need to derive a schedule $S = S_1, ..., S_T$, which are also defined in a matrix form.

$$S_t(i,j) = \begin{cases} 1 & \text{if } e_{ij} \in G \text{ is scheduled in } t \\ 0 & \text{Otherwise} \end{cases}$$

We formulate the utility optimization problem as follows,

$$\begin{aligned} minimize \quad & U = T^a \|P\|_1^b \\ s.t. \quad & \sum_{t=1}^{T} S_t = E; \\ & \forall i < j, S_j \times S_i = 0; \\ & HS_tP = N_0W; \ t = 1, ..., T \end{aligned}$$

Here, the first constraint function is to ensure that each link is scheduled exactly once. And the second constraint function makes sure that precedence constraints are satisfied. The third constraint, which is current unsolved problem, will serve as the SINR constraints with SIC involved. H should be a generalized path gain matrix and P is the vector of power assignment. N_0 is the noise density on frequency and W is the bandwidth.

With consideration of data rates and QoS, we set predefined data rate and QoS requirements to each link e_{ij} as R_{ij} and Q_{ij} respectively. Then we have

$$\frac{E_b}{N_0} = \frac{W}{R_{ij}} \frac{p_i h_{ij}}{N_0 W + \sum_{k \in V_t/\{i\}} p_k h_{kj} + \sum_{l \in V_c} p_l h_{lj}} \geq Q_{ij}$$
$$\Rightarrow \frac{W}{R_{ij} Q_{ij}} p_i h_{ij} - \sum_{k \in V_t/\{i\}} p_k h_{kj} - \sum_{l \in V_c} p_l h_{lj} \geq N_0 W$$

where, V_t is the set of current transmitting links of e_{ij} with different receivers and V_c is the set of current transmitting link sharing the same receiver with e_{ij} but canceled after e_{ij}.

A closely related literature addresses on the single-receiver-multiple-transmitter scenario. That means they only consider the interference cancellation at one receiver and cares nothing else from other links with different receiver. The SINR constraint function in that work is

$$\frac{W}{R_i Q_i} p_i g_i - \sum_{k>i} p_k g_k \geq N_0 W$$

which can be represented as a matrix function

$$\begin{pmatrix} \frac{W g_1}{R_1 Q_1} & -g_2 & -g_3 & \dots & -g_5 \\ 0 & \frac{W g_2}{R_2 Q_2} & -g_3 & \dots & -g_5 \\ 0 & 0 & \frac{W g_3}{R_3 Q_3} & \dots & -g_5 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & \frac{W g_n}{R_n Q_n} \end{pmatrix} \begin{pmatrix} p_1 \\ p_2 \\ p_3 \\ \dots \\ p_n \end{pmatrix} \geq N_0 W$$

We should define our H in the similar form of above matrix. However, how to extend the single receiver into multiple receiver case with SIC is most challenging.

Current path gain matrix are all link-oriented with receiver as the representatives. However, with SIC, one node may serve as receiver for multiple links. So in our model, it may be more desirable to use transmitters to represent the links.

II. Paper Study

Interference model is a critical part in wireless networking research. There are two commonly utilized interference models in current literatures: the physical model and the protocol model. The physical model is more realistic but requires global information and high computational complexity which acts as a main obstacle in designing efficient algorithms in wireless networks with inherent distributed nature. On the other hand, the protocol model is simpler to be applied in distributed implementation. However, its feasibility is always an argument. [1] addresses on the gap between these two models and shows the infeasibility of protocol model with certain examples. Analysis demonstrates that the value of interference range is a crucial factor in determining the performance gap. And a novel mechanism called “reality check” is proposed to alleviate the gap.

The main drawback of this work is that only qualitatively evaluation of interference range's effect on feasibility is conducted. But we have no idea on how to assign a proper value to "interference range" in order to minimize the feasibility gap between protocol mode and physical model.

[2] is a recent work on Minimum-Latency Aggregation Scheduling problem (MLAS) in multihop wireless networks. The problem is formulated with protocol interference model with unit transmission radius and $\rho \geq 1$ interference radius. The aggregation scheduling is decomposed into two steps: aggregation tree construction and link scheduling. In aggregation tree construction, a Connected Dominating Set (CDS), which serves as the inward arborescence, is derived with a Maximum Independent Set (MIS) coupled with some connecting nodes. A Breath-First-Search is utilized in this process. Nodes and links are labeled for further scheduling. The main idea is to sort the nodes in descending order of node degree in order to minimize the inductivity of the graph. Pipeline technique is implemented to accelerate the scheduling process.

References

[1] Y. Shi, Y.T. Hou, J. Liu and S. Kompella, *How to Correctly Use the Protocol Interference Model for Multi-hop Wireless Networks*, In proceedings of MobiHoc'09, May 18-21, 2009, New Orleans, Louisiana, USA.

[2] P.-J. Wan, S.C.-H. Huang, L. Wang, Z. Wan and X. Jia, *Minimum-Latency Aggregation Scheduling in Multihop Wireless Networks*, In proceedings of MobiHoc'09, May 18-21, 2009, New Orleans, Louisiana, USA.