Weekly Report (2010-02-04)

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I am working on two problems this week:

1) Implement the centralized algorithm in order to find some interesting properties for tree construction, link scheduling and power control.
2) Design the distributed algorithm to give a min-min solution, which first minimize the aggregation latency and then minimize the power consumption.

I. Distributed Algorithm

I have designed the skeleton for the algorithm and calculated some important parameters. More detailed parameters should be carefully assigned to ensure the correctness and efficiency.

The distributed algorithm is composed of two parts: tree construction and link scheduling. In the tree construction step, we construct the aggregation tree in a distributed fashion. Then, in the link scheduling step, a collision-free schedule, which fulfills the SINR requirement for each link, is executed to aggregate data from each node to the sink.

A. Tree Construction

We first label each node with a level and then construct the aggregation tree according to the node level.

1) **Node Level Labeling**: Starting from the sink node v_n, we conduct breadth-first search to find the minimum hop-distance from each node to the sink. Let the level of the sink node to be 0, the level of any node is exactly the minimum hop-distance to the sink.
2) **Aggregation Tree Construction**: Let the node set of level l is V_l. For each node $v_i \in V_l$, connect to the nearest neighbor of level $l-1$. However, simply constructing the tree with nearest neighbor mechanism is not optimal. In some cases, the nearest neighbor already has a large number of children which generate a high power demand for interference cancellation. So a switching algorithm should be executed to switch a level l child from the nearest neighbor to another level $l-1$ neighbor which suffers less power demand in interference cancellation. The parameters are being studied.

The minimum distance between any node pair is assumed as r. The maximum transmission range d_M is defined as follows.

$$\frac{P_M/d_M^\alpha}{N_0+I} = \beta$$
$$\Rightarrow d_M = (\frac{P_M}{\beta(N_0+I)})^{1/\alpha}$$

here, I is the bounded interference from concurrent senders with different receivers.

B. Link Scheduling

Each concurrent receiver should be separated by a distance of r_c. In fact, we have converted the SINR interference model into a graph-based model by bounding the interference.

Thus, for each receiver, the interference from concurrent senders for other receivers can be bounded as follows.

$$
\begin{aligned}
I \leq & 6 \sum_{i=1}^{+\infty} \sum_{m=0}^{\lfloor \log_{1+\beta} d_M/r \rfloor} P_M/(ir_c - d_M/(1+\beta)^m)^\alpha \\
& 6 \sum_{i=1}^{+\infty} \sum_{m=0}^{\lfloor \log_{1+\beta} d_M/r \rfloor} P_M/(i\sqrt{3}r_c - d_M/(1+\beta)^m)^\alpha \\
& + 12 \sum_{i=1}^{+\infty} \sum_{j=1}^{i} \sum_{m=0}^{\lfloor \log_{1+\beta} d_M/r \rfloor} P_M/(\sqrt{3(i+1/2)^2 + (j-1/2)^2} r_c - d_M/(1+\beta)^m)^\alpha \\
& + 12 \sum_{i=1}^{+\infty} \sum_{j=1}^{i} \sum_{m=0}^{\lfloor \log_{1+\beta} d_M/r \rfloor} P_M/(\sqrt{3(i+1)^2 + j^2} r_c - d_M/(1+\beta)^m)^\alpha
\end{aligned}
$$

II. THEORETICAL ANALYSIS

Theorem 1 (Aggregation Latency Upper Bound): The aggregation latency with successive interference cancellation is upper-bounded by n in worst case.

The proof is trivial.

Theorem 2 (Aggregation Latency Lower Bound): The aggregation latency with successive interference cancellation is lower-bounded by $\log_X n$, where $X = \log_{1+\beta} P_M/(N_0 \beta r^\alpha) + 1$.

Proof: Let the minimal distance between any node pairs to be r. We first consider the case when only one receiver is receiving data from multiple senders with *SIC*.

$$
\begin{aligned}
& \frac{P_M/r^\alpha}{N_0(1 + \sum_{i=1}^{X-1} \beta(1+\beta)^{i-1})} = \beta \\
\Rightarrow & P_M/r^\alpha = N_0 \beta (1+\beta)^{X-1} \\
\Rightarrow & X = \log_{1+\beta} P_M/(N_0 \beta r^\alpha) + 1
\end{aligned}
$$

X is the maximum possible number of senders that can be successfully scheduled to the same receiver with *SIC*. So the minimum tree depth can be $\log_X n$.

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Our objective is to have the theorem as follows.

Theorem 3 (Aggregation Latency of Distributed Algorithm): The distributed algorithm can complete the data aggregation in $O(D + \Delta)$ time slots, where D is the network diameter for the sink and Δ is the maximum node degree.