**Broadcast Routing in Energy Constrained Wireless Networks**

- **Communication Model**: Single Sender with multiple receivers
- **Medium**: Wireless with transmission attenuation (or path loss) factor \(2 \leq \alpha \leq 4\)
  - The power required to transmit to receiver \(R\) is proportional to \(|SR|^\alpha\)
  - For square loss medium \(|SR|^2\)
- **Constraint(s)**: Every node has limited battery resource

**Broadcast Advantage**

- **Broadcast Advantage**: Sender \(S\) with (omnidirectional antenna) transmitting at energy level to reach node \(A\) can reach all the nodes inside the circle with radius \(|SA|\) for free

**Impact of physical layer on network layer decisions**

- **Problem 1**: Develop Routing Algorithm(s) so that the sender \(S\) can transmit to all the receivers with minimum total energy expenditure
- **Problem 2**: Incorporate the battery power/energy into the model and extend the lifetime of the network by conserving each node’s battery
- Can this be done efficiently? (with reasonable amount of computations and some guarantees about the convergence to optimal solutions)

**An Example**

Problem: Find the shortest path with min total energy from Node \(A\) to all other nodes

**MST Solution without BA**

Problem: Find the shortest path with total Min energy from Node \(A\) to all other nodes

Assume: Pathloss factor = 2; link weights are distances

Total Power of the Tree = 4 + 1 + 1 + 1 + 4 = 11 units
Solution with BA (Exhaustive Search)

Problem: Find the broadcast tree with minimal total power expenditure

Solution: A->B, E->F : Total power = 4 + 4 = 8 units

How to develop a faster solution?

• Broadcast Incremental Power (BIP) Algorithm

• Input: given an undirected weighted graph \( G(N, A) \), where \( N \) : set of nodes, \( A \) : set of edges

• Initialization: set \( T := \{S\} \) where \( S \) is the source node of multicast session. Set \( P(i) := 0 \) for all \( 1 \leq i \leq |N| \) where \( P(i) \) is the transmission power of node \( i \).

• Procedure:
  •  
  • while \( |T| \neq |N| \)
  •  
  • do find an edge \( (i, j) \in T \times (N - T) \) such that
  •  
  • incremental power \( \Delta P_{ij} = d_{ij}^\alpha - P(i) \) is minimum.
  •  
  • add node \( j \) to \( T \), i.e., \( T := T \cup \{j\} \).
  •  
  • set \( P(i) := P(i) + \Delta P_{ij} \).

Execution of the BIP Algorithm

<table>
<thead>
<tr>
<th>Iteration</th>
<th>T</th>
<th>P(i)</th>
<th>Total Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>( {A} )</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>( {A, B} )</td>
<td>1, 1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>( {A, B, C} )</td>
<td>1, 1, 1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>( {A, B, C, E} )</td>
<td>1, 1, 4</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>( {A, B, C, E, F} )</td>
<td>1, 1, 4, 1</td>
<td>9 (not optimum)</td>
</tr>
</tbody>
</table>

BIP Solution with BA

Problem: Find the broadcast tree with minimal total power expenditure

Solution: A->B, D->E, E->F : Total power = 4 + 4 = 8 units

Effect of Battery Lifetime on Relay Nodes

• In the example
  • Set Source battery to be 10K units
  • All other nodes 1K units
  • Node D has to relay all the traffic with same power as the source
    • Assume that at unit time unit data is transmitted.
    • Battery of node D dies in 250 units of time. Network fails

Effect of Battery Lifetime on Relay Nodes

• As the battery gets depleted, the residual energy becomes a critical resource
  • Incorporate the residual battery power into cost function
  • Power to transmit from \( A \) to node \( D \) is \( W_A|AD|^\alpha \) where \( W_A = E_A/(E_A - E_A, spent) \)
Additional Information

• As the battery gets depleted, the residual energy becomes a critical resource
  – Incorporate the residual battery power into cost function
  – Power to transmit from node A to node D is $W_A|AD|$ where $W_A = E_A/(E_A - E_{A, spent})$