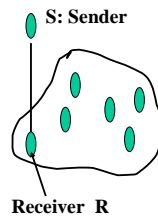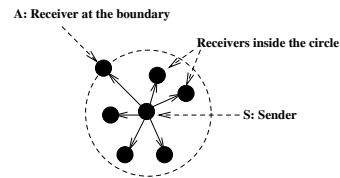## Broadcast Routing in Energy Constrained Wireless Networks

- **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

S: Sender

Receiver R

Broadcast Advantage

A: Receiver at the boundary

Receivers inside the circle

S: Sender

- **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*

Broadcast Routing in Energy Constrained Wireless Networks

- **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)


Impact of physical layer on network layer decisions

- Medium has square law path loss
- Sender **S** needs to transmit identical packet to receivers M_1 and M_2
- Decision to be made by **S**
  - Route to M_1 and let M_1 route to M_2
  - Route to M_2 (and M_1 will receive it due to broadcast advantage)

S: Sender

M_1, M_2 : Receivers

M_2

d_2

d_{12}

q

S

d_1

M_1
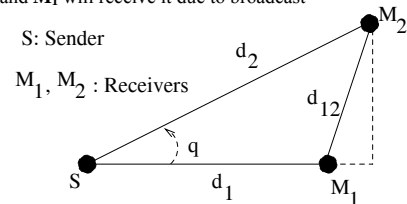
An Example

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

5

B 3 **C** 5

2

Source node A 2 3 1 **F**

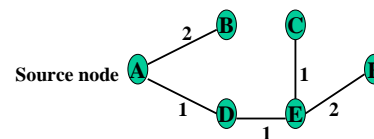1 **D** **E** 2

1
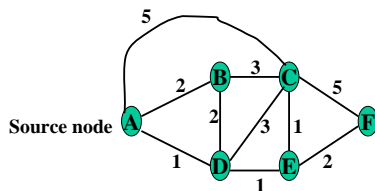
MST Solution without BA

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

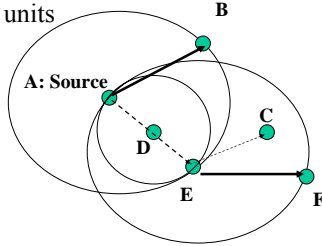Assume: Pathloss factor =2; link weights are distances

Total Power of the Tree = 4 +1+1+1+4= 11 units

2 **B** **C**

Source node A 1 **F**

1 **D** **E** 2

1

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., $T := T \cup \{j\}$.
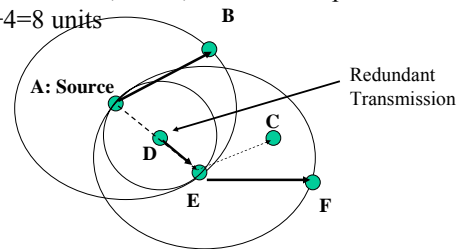- **set** $P(i) := P(i) + \Delta P_{ij}$.

Execution of the BIP Algorithm

Iteration #	T	P(i)	Total Power
0	{A}U{D}	P(A) =1	1
1	{A,D}U{E}	P(A)=1, P(D)=1	2
2	{A,D,E}U{C}	P(A)=1, P(D)=1, P(E)=1	3
3	{A,D,E,C}U{F}	P(A)=1, P(D)=1, P(E)=4	6
4	{A,D,E,C,F}U{B}	P(A)=4, P(D)=1, P(E)=4	**9 (not optimum)!**

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

Redundant Transmission

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 **A** to node **D** is $W_A|AD|^\alpha$ where $W_A = E_A/(E_A - E_{A, spent})$