Power-Aware Localized Routing in Wireless Networks

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GOALS OF THIS PAPER

- Design routing protocols with the following properties:
  1) Minimize energy required per routing task.
  2) Loop-freedom.
  3) Maximize the number of routing tasks that a network can perform.
  4) Minimize communication overhead.
  5) Avoid memorizing past traffic or route.
  6) Localized algorithms.
  7) Single-path routing algorithms.
  8) Maximize delivery rate.

OUTLINE

- Introduction
- Some properties of power adjusted transmissions
- Power saving routing algorithms
- Experiment results
- Conclusions

INTRODUCTION

- Wireless networks are likely to be widely deployed in the near future because they greatly extend our ability to access information remotely.
- We define a new power-cost metric based on the combination of both node's lifetime and distance-based power metrics.

INTRODUCTION(cont'd)

- Power, cost, and power-cost *localized* routing algorithms decisions solely on the basis of *location of their neighbors* and *destination*.
- *The power-aware routing algorithm* attempts to minimize the total power needed to route a message between a source and a destination.
- *The cost-aware routing algorithm* is aimed at extending the battery's worst-case lifetime at each node.
- The combined *power-cost localized routing algorithm* attempts to minimize the total power needed and to avoid nodes with a short battery's remaining lifetime.

SOME PROPERTIES OF POWER ADJUSTED TRANSMISSIONS

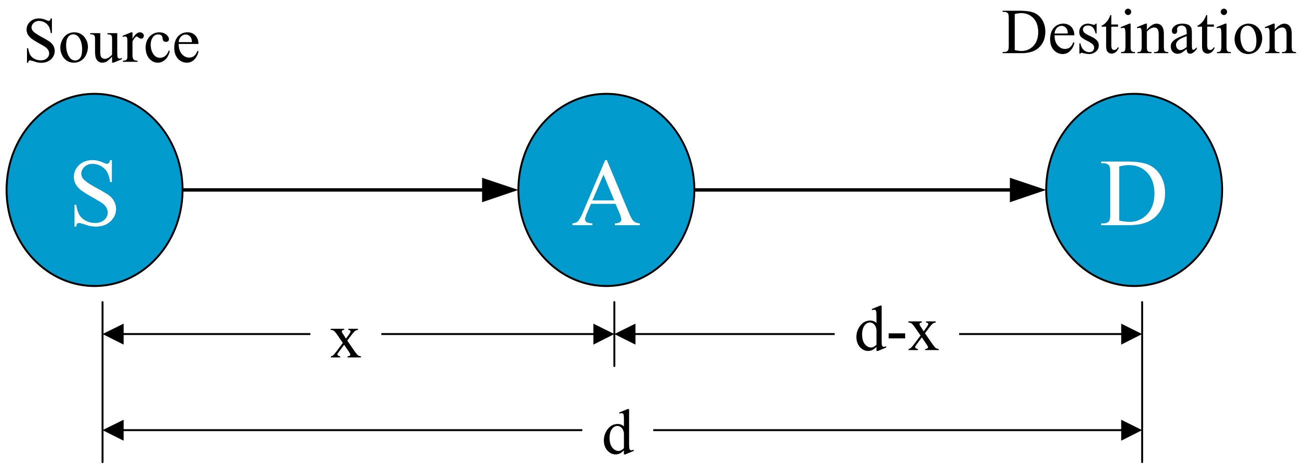
- Power needed for the transmission and reception of a signal is:

$$u(d)=ad^{\alpha}+c$$

where c is a constant factor, a is a physical related factor

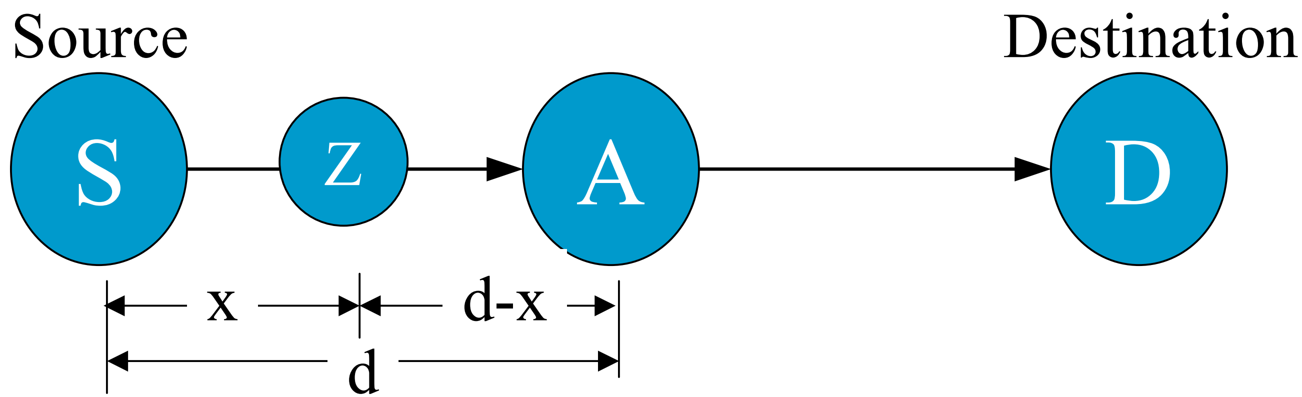
- For example, in RM-model[22], α=4, a=1, c=2*10^8

SOME PROPERTIES OF POWER ADJUSTED TRANSMISSIONS(cont'd)



- ***Lemma 1.*** If *$d > (c/(a(1-2^{1-\alpha})))^{1/\alpha}$*, then there exists intermediate node A between source S and destination D so that the retransmission will save the energy. *The greatest power saving is obtained when A is in the middle of SD.*

SOME PROPERTIES OF POWER ADJUSTED TRANSMISSIONS(cont'd)



- ***Lemma 2.*** If $d > (c/(a(1-2^{1-\alpha})))^{1/\alpha}$, then the greatest power savings are obtained when the interval SD is divided into n > 1 equal subintervals, where n is the nearest integer to $d(a(\alpha-1)/c)^{1/\alpha}$. The minimal power is then

$$dc(a(\alpha-1)/c)^{1/\alpha} + da(a(\alpha-1)/c)^{(1-\alpha)/\alpha}$$

SOME PROPERTIES OF POWER ADJUSTED TRANSMISSIONS(cont'd)

- ***Theorem 1***. Let *d* be the distance between the source and the destination. The power needed for direct transmission is $u(d)=ad^{\alpha}+c$ which is optimal if $d \leq (c/(a(1-2^{1-\alpha})))^{1/\alpha}$. Otherwise, n -1 equally spaced nodes can be selected for retransmissions, where $n = d(a(\alpha-1))^{1/\alpha}$ (rounded to the nearest integer), producing minimal power consumption of about

$$v(d)=dc(a(\alpha-1)/c)^{1/\alpha} + da(a(\alpha-1)/c)^{(1-\alpha)/\alpha}$$

POWER SAVING ROUTING ALGORITHMS

- Note that a power metric is presented.

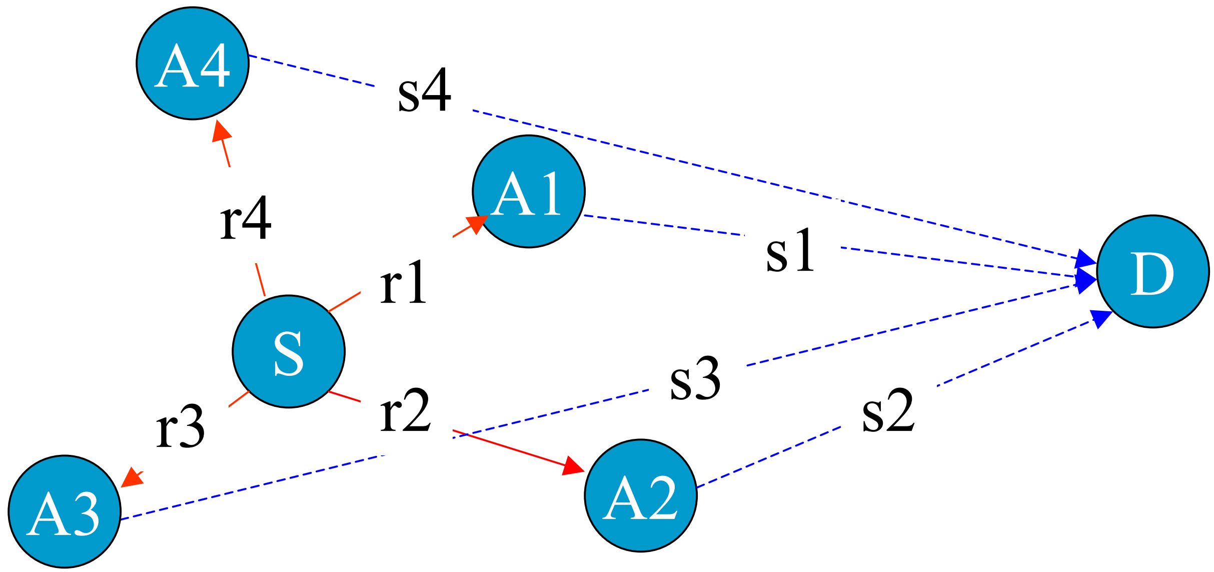
$$u(d)=ad^{\alpha}+c$$

- Dijkstra's shortest (weighted) path algorithm and above theorem are also known.
- *Demand-based* and *single-path routing* is considered.

POWER SAVING ROUTING ALGORITHMS (cont'd)

- Several routing algorithms are proposed.
  - *SP-power algorithm*
  - *Power efficient routing algorithm*
  - *Cost efficient routing algorithm*
  - *Power-cost efficient routing algorithm*

Power efficient routing algorithm



- The power needed for the transmission from S to A_i is $u(r_i)=ar_i^{\alpha}+c$.
- The power needed for the transmission from A_i to D is estimated by

$$v(s_i)=s_i c(a(\alpha-1)/c)^{1/\alpha}+s_i a(a(\alpha-1)/c)^{(1-\alpha)/\alpha}$$

Power efficient routing algorithm (cont'd)

- Delivery node selection method:
  - *Each node S will select one of its neighbors A which will minimize*

$$p(S, A) = u(r_i)+v(s_i)$$

$$= ar_i^{\alpha}+c+(s_i c(a(\alpha -1)/c)^{1/\alpha} + s_i a(a(\alpha -1)/c)^{(1-\alpha)/\alpha}$$

- The authors make a fair assumption that the power consumption for the rest of routing algorithm is equal to the optimal one.
- The assumption is unrealistic but it is fair to all nodes.

Power efficient routing algorithm (cont'd)

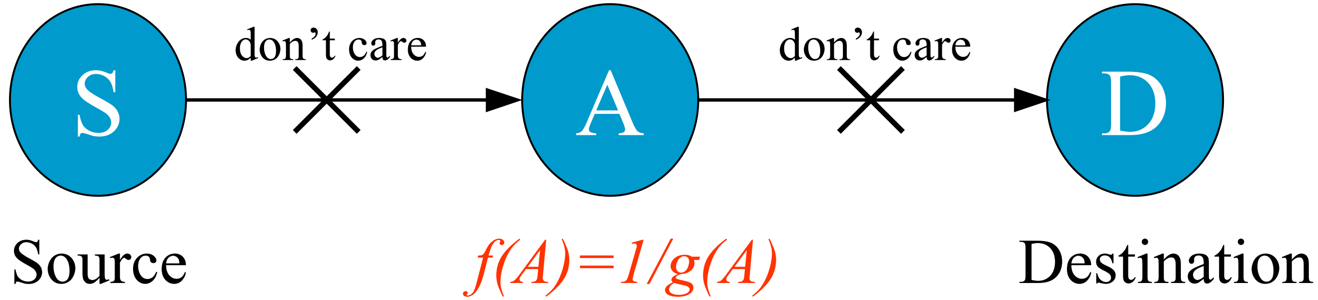
- A generalized power efficient routing algorithm may attempt to minimize $p(S, A) = u(r_i)+tv(s_i)$, where t is a network parameter.
- *Algorithm:*

```
Power-routing(S,D);
  A:=S;
  Repeat
        B:=A;
        Let A be neighbor of B that minimizes
            p(B, A) = u(r) + tv(s);
        Send message to A
  until A=D(* destination reached *) or A=B (* delivery failed *)
```

- *This algorithm induces the selection of the nearest path from source to the destination.(The same result can be obtained via Dijkstra's shortest weighted path algorithm)*

Cost efficient routing algorithm

- In [26], the cost of each node is equal to $f(A)=1/g(A)$, where $g(A)$ denotes the remaining lifetime ($g(A)$ is normalized to be in the interval [0,1)).
- The cost c(A) of a route from S to D via neighboring node A is the sum of the cost $f(A)=1/g(A)$ of node A and the estimated cost of route from A to D.



Cost efficient routing algorithm (cont'd)

- What is the cost of other nodes on the remaining path?
  - We assume that this cost is proportional to the number of hops between A and D.
  - The cost is estimated by td / R, where $d = |AD|$, R is the radius of transmission power, and t is to be investigated separately.

Cost efficient routing algorithm (cont'd)

- We have considered the following choices for factor t:
  - t is a constant number, which may depend on network conditions.
  - t = f(A) (that is, assuming that remaining nodes have equal cost as A itself).
  - t = f'(A), where f'(A) is the average value of f(X) for A and all neighbors X of A.
  - t = 1/g'(A), where g'(A) is the average value of g(X) for A and all neighbors X of A.

Cost efficient routing algorithm (cont'd)

- The cost c(A) of a route from S to D via neighboring node A is estimated to be $c(A) = f(A)+td/R$ (Authors suggest use of $c(A) = f(A)td/R$).
- *Algorithm:*

Cost-routing(S,D);
    A:=S;
    Repeat
        B:=A;
        Let *A* be neighbor of *B* that minimizes *c(A);*
        If *D* is neighbor of *B*
            then send to *D* **else** send to *A*
    until *D* is reached or *A=B;*

- *This algorithm does not consider the power consumption of the distance from node to node.*

Power-cost efficient routing algorithm

- We propose two different ways to combine power and cost metrics into a single power-cost metric, based on the product and sum of two metrics, respectively.
- Product: $power\text{-}cost(S,A) = f(A)u(r)$ (where |SA| = r)
- Sum: $power\text{-}cost(S,A) = \alpha u(r) + \beta f(A)$

Power-cost efficient routing algorithm(cont'd)

- The power-cost efficient routing algorithm may be described as follows: Let A be the neighbor of B (node currently holding the message) that minimizes

$$pc(B,A) = power\text{-}cost(B,A) + v(s)f'(A)$$

- *Algorithm:*

Power-cost-routing(S,D);
    A:=S;
    Repeat
        B:=A;
        Let A be neighbor of B that minimizes
          $pc(B, A) = power\text{-}cost(B, A) + v(s)f'(A)$;
        Send message to A
    until A=D (* destination reached *)
          or A=B (* *delivery failed* *);

PERFORMANCE EVALUATION

- Static unit graphs is used.
- Routing zones are in the different size of the square of 10, 100, 200, 500, 1000, 2000, 5000 units.
- High connectivity environment in which every node has a average degree 10.

PERFORMANCE EVALUATION OF POWER EFFICIENT ROUTING ALGORITHM

TABLE 1
Power Consumption of Routing Algorithms

method/size	10	100	200	500	1000	2000	5000
SP-Power	3577	4356	6772	20256	62972	229455	1404710
SP	3578	4452	7170	25561	92438	358094	2236727
Power	3619	4457	6951	21331	69187	261832	1647964
GEDIR	3619	4460	7076	24823	89120	344792	2152891
DIR	3928	4681	7046	23033	81001	311743	1942952
MFR	3644	4523	7264	25845	93150	361021	2254566
NC	7604	8271	10523	25465	80136	297580	1833993
Random	5962	7099	10626	34382	121002	465574	2896988
2-GEDIR	3587	4452	7148	25399	91570	354980	2216528
2-DIR	3937	4764	7386	25109	89371	344644	2148913
2-MFR	3603	4478	7208	25738	92816	359491	2248876

PERFORMANCE EVALUATION OF COST AND POWER-COST EFFICIENT ROUTING ALGORITHMS

- Each node is assigned an energy level at random in the interval [*minpow*, *maxpow*]

TABLE 2
Number of Iterations Before One Node in Each Method Dies

method/trial count	10	100	200	500	1000	2000	5000
SP	289	713	1412	668	647	454	275
SP-Power	342	865	1710	983	1114	796	482
SP-Cost	674	1703	3540	1686	1590	1066	646
SP-Power*Cost	674	1697	3530	1776	1838	1230	728
SPPower+Cost	647	1668	3495	1725	1688	1124	682
Power	379	954	1843	1009	1162	789	469
Cost-iii	624	1630	3255	1594	1479	988	601
Cost-ii	637	1616	3304	1651	1494	991	602
PowerCostP	671	1616	3127	1522	1522	1053	600
Power*Cost	662	1609	3118	1513	1528	1056	617
Power+Cost	660	1611	3180	1664	1757	1179	712
PowerCost2	631	1537	3211	1676	1716	1152	686
1-GEDIR	373	941	1814	832	849	548	318
1-DIR	345	921	1741	831	902	603	355
1-MFR	375	909	1775	800	797	525	316
1-NC	204	551	1268	809	931	668	414
Random	201	481	889	546	512	312	202

[80K,90K] [200K,300K] [500K,1M] [750K,1.5M] [3M,4M] [8M,10M] [30M,40M]

PERFORMANCE EVALUATION OF COST AND POWER-COST EFFICIENT ROUTING ALGORITHMS(cont'd)

TABLE 3
Average Remaining Power Level at Each Node

method/power	10	100	200	500	1000	2000	5000
SP-Cost	44381	133245	395592	618640	1857188	4819903	19238265
SP-Power*Cost	44437	133591	396031	642748	2067025	5686092	23187052
SPPower+Cost	46338	136490	406887	646583	1972185	5252813	21081420
Cost-iii	43996	129608	410610	656349	2053190	5370162	21338314
Cost-ii	39831	120785	377549	619221	2022771	5335936	21233992
PowerCostP	30561	127819	421927	712958	2299590	6058424	24782129
Power*Cost	27434	126066	416889	712033	2286840	6030614	24419832
Power+Cost	27520	126201	409208	666907	2091211	5658144	22622947
PowerCost2	33563	131804	401174	652199	2078140	5684752	23136193

CONCLUSIONS

- This paper described several localized routing algorithms that try to minimize the total energy per packet and/or lifetime of each node.
- The algorithms must have the information about the location of the destination.
- QoS routing should be combined with power-cost aware routing.
- Routing failure is not discussed in this paper.
- There are lots of parameters in the paper can be discussed.