Broadcast Storm Problem

Broadcasting Approaches

Approach

Reliable:
-Guaranteed to reach all nodes.
-Usually require >= 1 hop info

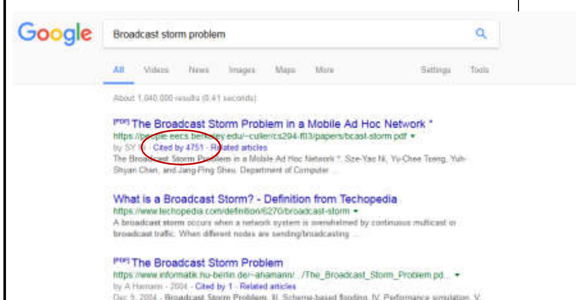
Unreliable:
-No guarantee to reach all
-Best Effort service
-Usually requires no topology information

First paper on Broadcasting

"The Broadcast Storm Problem in a Mobile Ad hoc Network"

Discusses problem if we broadcast with ZERO-topology knowledge (flooding) and possible remedies

Citation count of the paper



Storm in Internet

Subject: Hold on! Don't throw out this message yet!
Date: Wed, 30 Jun 1999 07:35:40 +0800 (CST)
From: Rory.Bellows@chu.edu.tw
To: you@chu.edu.tw

Dear Sir or Madam,

Allright, I'm not going to give you any bull. This is "junk" mail, but if you will please just give me 60 seconds of your time and read the next paragraph, maybe I can change your mind. Just 60 seconds. What have you got to lose?

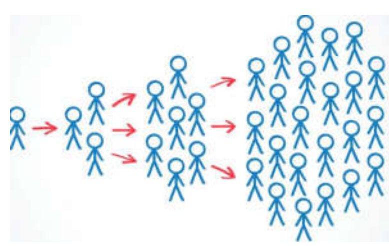
Below is a message I got last month. I said "junk," and was dragging the icon to my trash can when I figured "what the hell," and began reading it. I ALWAYS throw stuff like this out. But I read. And now I'm rolling in $$$. This works and I'm not kidding. At first it sounds like your typical "pyramid scheme" scam, but it's not - the difference is that you're actually selling a product! I won't go into the details right now, if you're interested you can keep reading the rest of the message. I just want to say a couple things. First, don't take my word for it that this works. Use your own head. Just read this message and think about the process logically. You'll see that it won't fail! Second, just make sure you follow the instructions TO THE LETTER. I can't stress that enough. ...

JUST DO IT!! Yeah, it's a long message to read, but it's worth it!

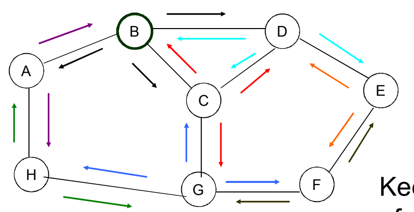
Thanks,
Rory

... (a 5-page-long email)

Storm in FB

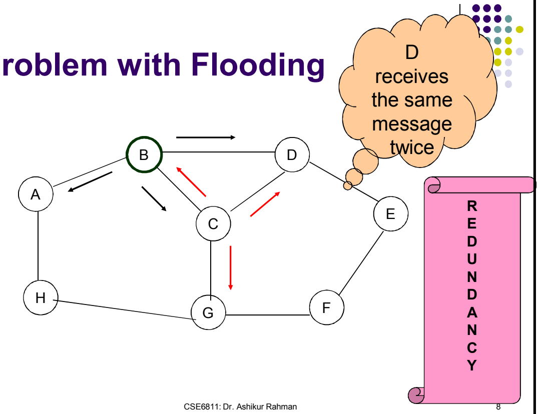


First approach: Flooding (with no Topology Knowledge)

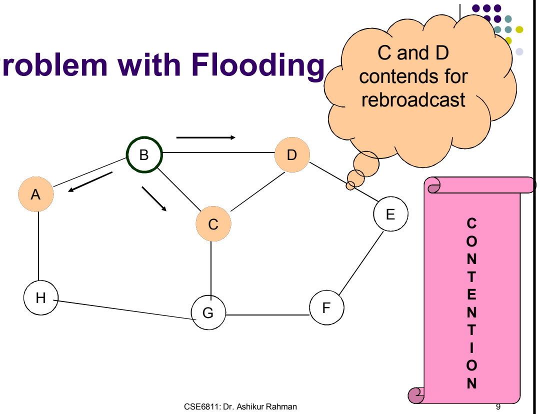


Keep track of packet signature

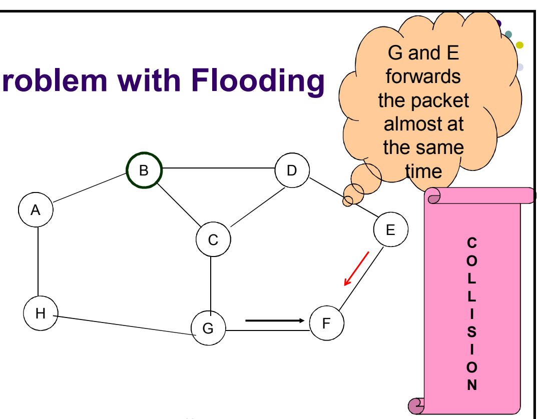
Problem with Flooding



Problem with Flooding



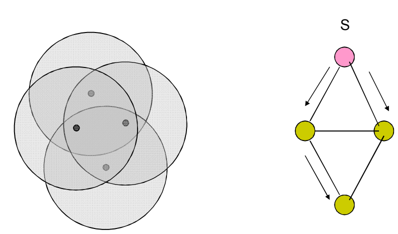
Problem with Flooding



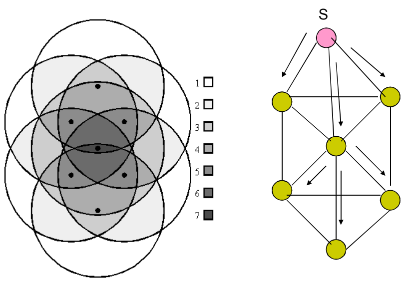
Broadcast Storm

Redundancy + Contention + Collision
= Broadcast Storm

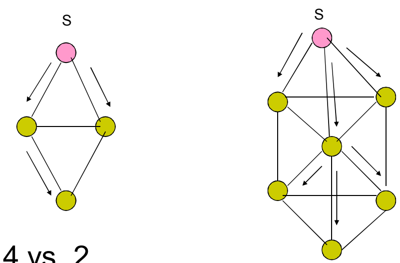
Analysis of Redundancy



Analysis of Redundancy



Analysis of Redundancy



4 vs. 2

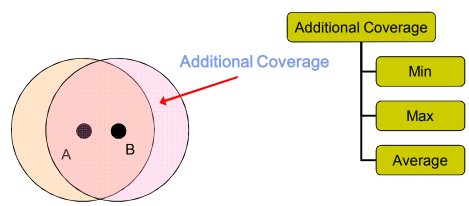
7 vs. 2

How to Mathematically quantify Redundancy?

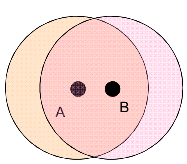
- We can figure out minimum number of forwarding needed to complete a broadcast
  - Anything extra is redundant
  - Problem:
    - Depends on node density
    - Finding minimum number of forwarding: hardest part

Solution:
Try to quantify in terms of coverage area

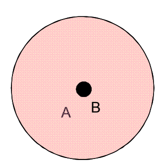
Concept of Additional Coverage



Concept of Additional Coverage

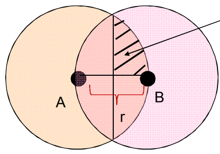


Concept of Additional Coverage

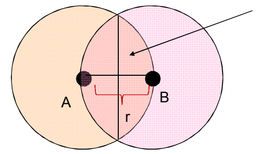


Additional Coverage (Max)

$$\int_{r/2}^{r} \sqrt{r^2 - x^2}\, dx$$



Additional Coverage (Max)



$$\int_{r/2}^{r} \sqrt{r^2 - x^2}\, dx$$

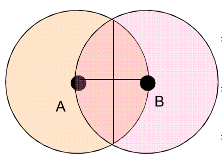
$$x = r \sin\theta$$

$$dx = r \cos\theta d\theta$$

$$x = r \Rightarrow \theta = \frac{\pi}{2}$$

$$x = r/2 \Rightarrow \theta = \frac{\pi}{6}$$

Additional Coverage (Max)



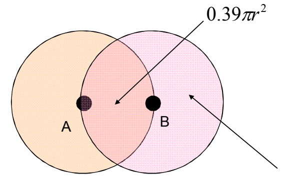
$$4 \times \int_{\pi/6}^{\pi/2} \left(\sqrt{r^2 - r^2 \sin^2\theta} \right) r \cos\theta d\theta$$

$$= 4 \times r^2 \int_{\pi/6}^{\pi/2} \left(\cos^2\theta d\theta \right)$$

$$= r^2 \left[\frac{2\pi}{3} - \frac{\sqrt{3}}{2} \right]$$

$$= 0.39\pi r^2$$

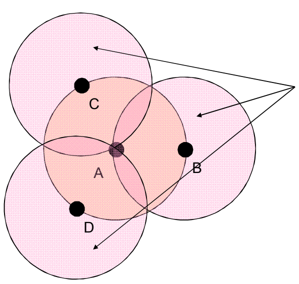
Additional Coverage (Max)



$0.39\pi r^2$

$\pi r^2 - 0.39\pi r^2 = 0.61\pi r^2$

Additional Coverage (Average)



$0.61\pi r^2$

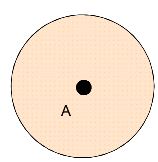
Average:

= total additional coverage/ total nodes

$= 0.61\pi r^2$

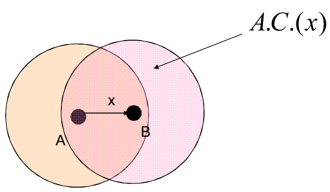
Generalized

$$\text{Average additional coverage} = \frac{\text{Additional Coverage for all nodes within TX range of A}}{\text{Total number of nodes within TX range of A}}$$

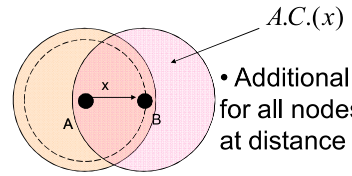


- *μ* node density (NODES/METER^2)
- *total nodes* = $\pi r^2 \times \mu$

Additional Coverage of All nodes?



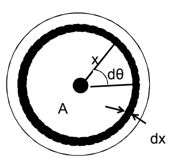
Additional Coverage of All nodes?



- Additional Coverage for all nodes located at distance *x*,

= *A.C.(x)* × *Number of nodes at distance x*

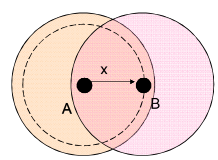
Number of nodes at distance x



- μ node density

Number of nodes at distance x
$= \text{Area of strip} \times \text{Node density}$
$= 2\pi x \, dx \, \mu$

Average



- Additional Coverage for all nodes located at distance *x*,

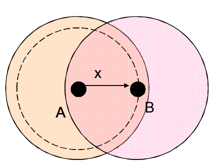
= *A.C.(x)* × *Number of nodes at distance x*

$= 2\pi\mu x \times A.C.(x)dx$

- *x* can vary from 0 to r
- Additional Coverage for all nodes within TX range of A, $\int_0^r 2\pi\mu x \times A.C.(x)dx$

Average

Average = (Additional Coverage for all nodes within TX of A)/Total number of nodes

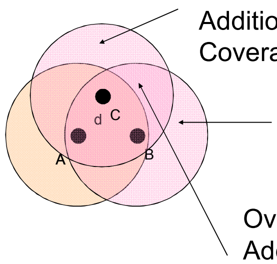


$$\frac{\int_0^r 2\pi\mu x \times A.C.(x)dx}{\pi\mu r^2}$$
$$= 0.41\pi r^2$$

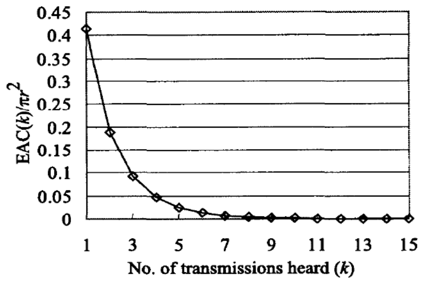
Summary of additional Coverage by a single node

$$\text{Min} = 0$$
$$\text{Max} = 0.61\pi r^2 = 61\%$$
$$\text{Average} = 0.41\pi r^2 = 41\%$$

Situation becomes worse when coverage overlaps

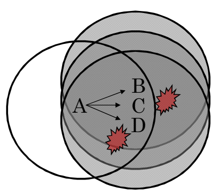


Empirical Additional Coverage

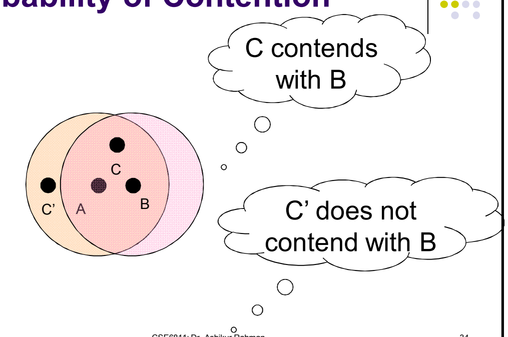


Analysis of Contention

- When a host broadcasts, its neighbors are likely to contend with each other for the medium.
  - A ==> B, C, D
  - B, C, D could seriously contend with each other.

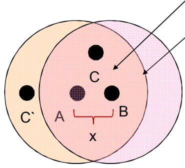


Probability of Contention

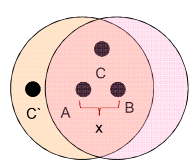


Probability of Contention

$$P(x) = \frac{S_{A \cap B}}{\pi r^2} = \frac{INTC(x)}{\pi r^2}$$



Average Contention



Probability of contention for all B located at distance x = $2\pi x \times P(x) \times dx$

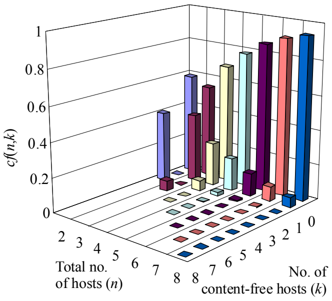
Average,

$$\frac{\int_0^r 2\pi x \times P(x)dx}{\pi r^2}$$

$= 59\%$

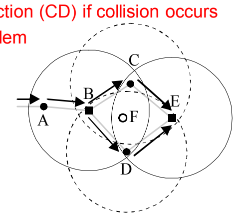
More nodes more contention

- *cf(n, k):* The probabilities of having *k* contention-free hosts among *n* receiving hosts.



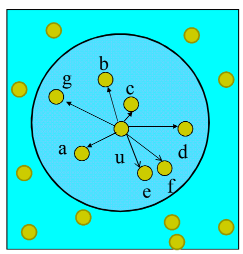
Analysis of Collision

- Higher Possibility of Collision:
  - Rebroadcasts are likely to start at the same time.
  - lack of RTS/CTS dialogues
  - lack of collision detection (CD) if collision occurs
  - hidden terminal problem

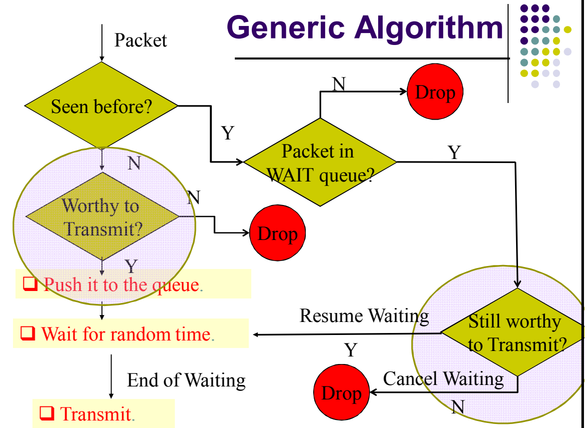


Solution to Broadcast storm?

- Reduce contention and collision:
  - Include randomness
- Reduce Redundancy:
  - Inhibit some nodes from re-broadcasting
    - Do it intelligently



Generic Algorithm

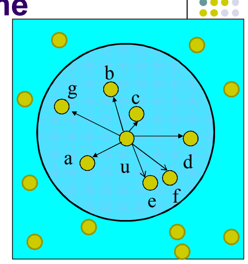


How to determine worthiness?

- Reduce Broadcast Storm
  - Probabilistic scheme
  - Counter based scheme
  - Distance based scheme
  - Location based scheme
  - Cluster based scheme

Probabilistic scheme

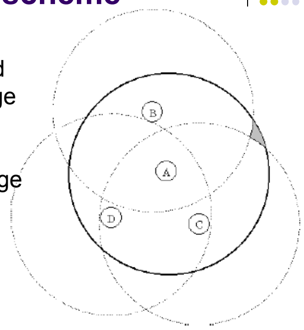
- Rebroadcast by "Tossing a Die"
- A host always rebroadcasts with a certain probability P.
- Let P = 80%
  - Generate a Random number between 1 to 100, broadcast if the generated number is less than 80



•When P = 1, this is flooding.
•A smaller P will reduce the storm effect.

Counter based scheme

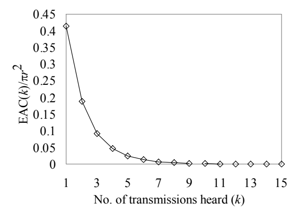
Node A has heard the same message 3 times before forwarding, little additional coverage



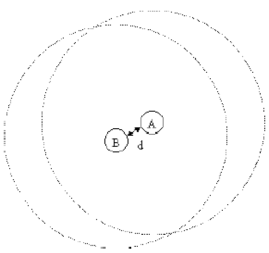
$$A.C.(x) \propto \frac{1}{k}$$

Counter based scheme (continue)

- **If a host has received the same broadcast packet more than C times,**
  - then do not rebroadcast.
- **Additional Coverage**
  - 1 time => 41%
  - 2 times => 19%
  - 3 times => 9%
  - 4 times => 5%
  - > 4 times, very little extra area



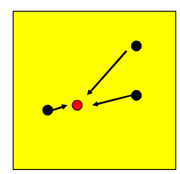
Distance based scheme



For closely located two nodes there is a marginal difference in their coverage area

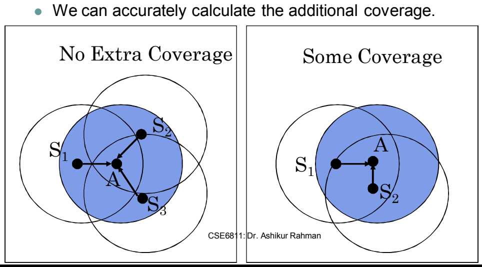
Distance based scheme

- Calculate the distance to the sending host.
- d_{min} = Min{ the distance to each sending host }
- If d_{min} < D (a threshold), then do not rebroadcast.
- How to find distance:
  - signal strength
  - GPS devices



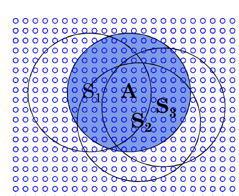
Location based scheme

- From GPS to obtain the sender's location.
- Let (x1, y1), (x2, y2), (x3, y3), ..., (xk, yk) be locations of senders.
  - We can accurately calculate the additional coverage.



Difficult computation

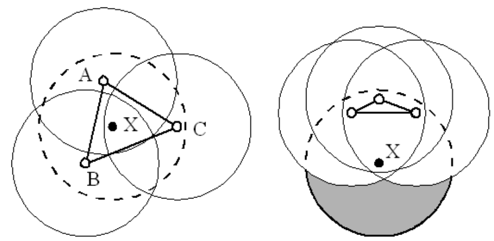
- Involve complicated math to calculate the extra coverage.
  - A lot of calculus!
- Approximation:
  - grid simulation



Modified location based scheme

- Polygon Test:
  - If a node is within the polygon formed by the locations of senders, then DO NOT rebroadcast. (Fig. (a))
  - Otherwise, rebroadcast. (Fig. (b))
  - If a host is within the convex, the maximum additional coverage is well below 22%.

Modified location based scheme



Cluster based scheme

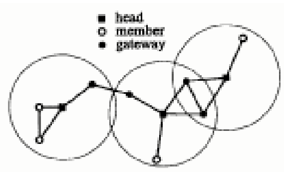


Figure 6: An example of a clustered MANET. Clustering provides a host the connectivity information of its surroundings.

Simulation parameters

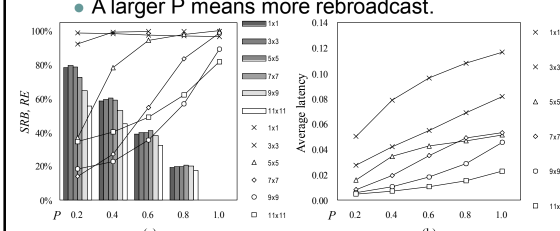
- no of hosts = 100
- transmission radius = 500 meters
- packet size = 280 bytes
- transmission rate = 1 M bits/sec
- broadcast arrival rate: 1 per sec. to the whole map
- map: (1 unit = 500 meters)
  - 1x1, 3x3, 5x5, 7x7, 10x10
- IEEE 802.11 without PCF (point coordination function)

Performance metrics

- Reachability = % of nodes receiving the broadcast.
- Latency = time to complete a broadcast
- Saved Rebroadcast = (r - t)/r
  - r = number of nodes receiving the broadcast.
  - t = number of nodes that rebroadcast

Probability based

- We vary P = 0.2, 0.3, ..., 1 to observe the performance.
  - A larger P means more rebroadcast.

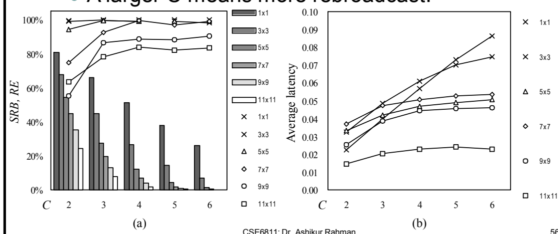


Observation

- Reachability:
  - In smaller maps, a low P is sufficient to achieve high reachability.
  - A larger P is needed in a larger map.
- Saved Rebroadcast:
  - linear with respect to P
- Latency:
  - Interestingly, in smaller areas, broadcast tends to complete in a slower speed. (due to higher node density)

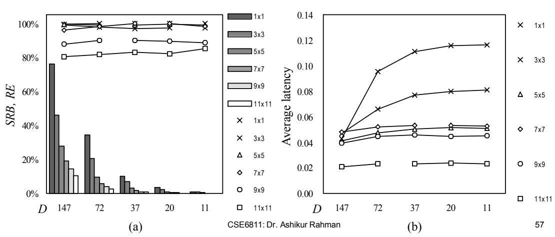
Counter based

- We vary C = 2, 3, ..., 6 to observe the performance.
  - A larger C means more rebroadcast.



Distance Based scheme

- We vary D = 147, 72, 37, 20, 11 to observe the effect.
  - Smaller D means more rebroadcasting.

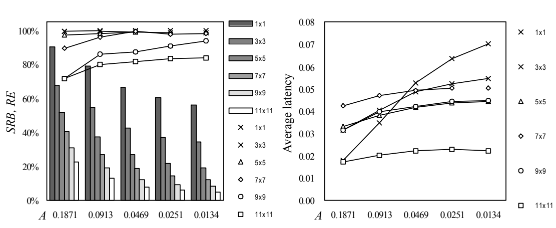


Observation

- Why choosing D=147?
  - addition coverage = 0.187, equal to that of C=2
- Reachability:
  - All look good, close to flooding.
- Saved Rebradcast:
  - not much
- Latency:
  - smaller area has higher latency

Location based scheme

- We vary A (addition coverage) from 0.1 to 0.01.
  - Smaller A means more rebroadcast.



Observation

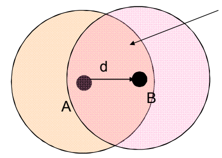
- Why choosing A=0.187?
  - This is additional coverage offered by C=2.
- Best performance over all the above schemes!

Drawbacks

- Best effort service
  - A miss may cause a significant portion of the network unreachable.
- Sensitive to threshold values
  - Sparse networks require more rebroadcast (high threshold value)
  - Dense networks require less rebroadcast (low threshold value)
  - How to choose appropriate threshold value????

(no hope)

Extra



$$INTC(d) = 4 \times \int_{d/2}^{r} \sqrt{r^2 - x^2}\, dx$$

$$AC(d) = \pi r^2 - INTC(d)$$
$$= \pi r^2 - 4 \times \int_{d/2}^{r} \sqrt{r^2 - x^2}\, dx$$