Chapter 9. Broadcast Storm Problem in a Mobile Ad Hoc Network

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Dec. 2006

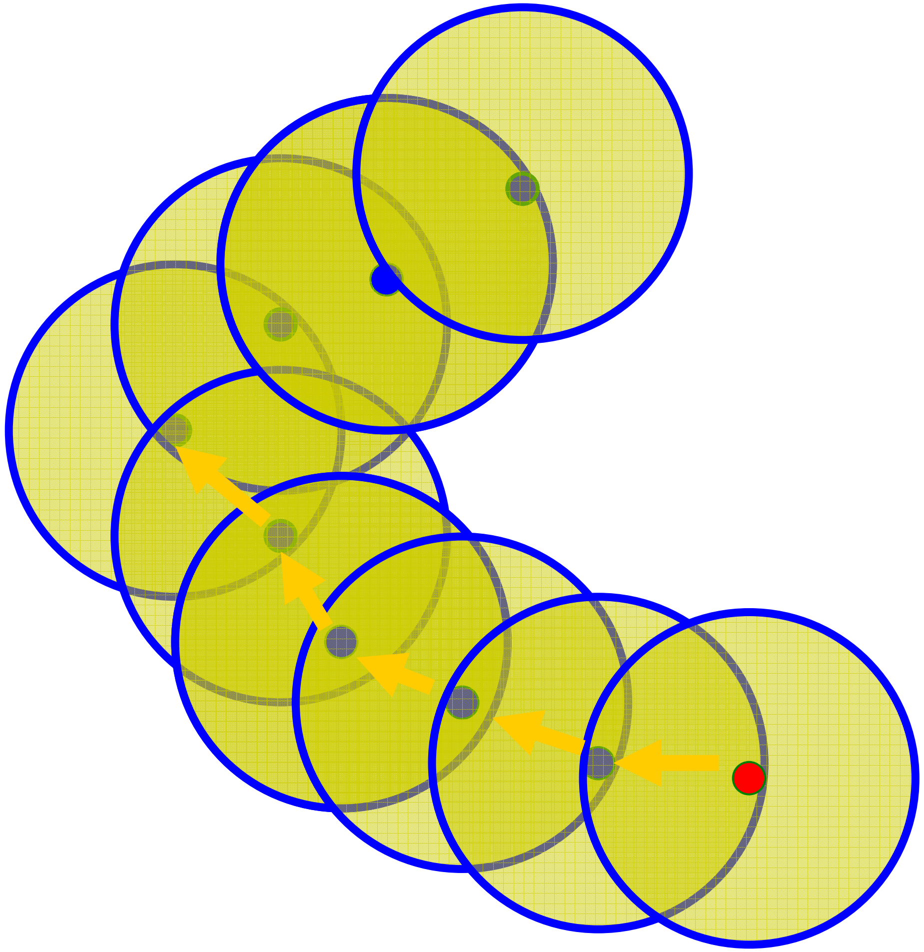
Outline

- Preliminaries
- Mechanisms to Reduce Redundancy, Contention, and Collision
- Performance Simulation
- Conclusion

Preliminaries

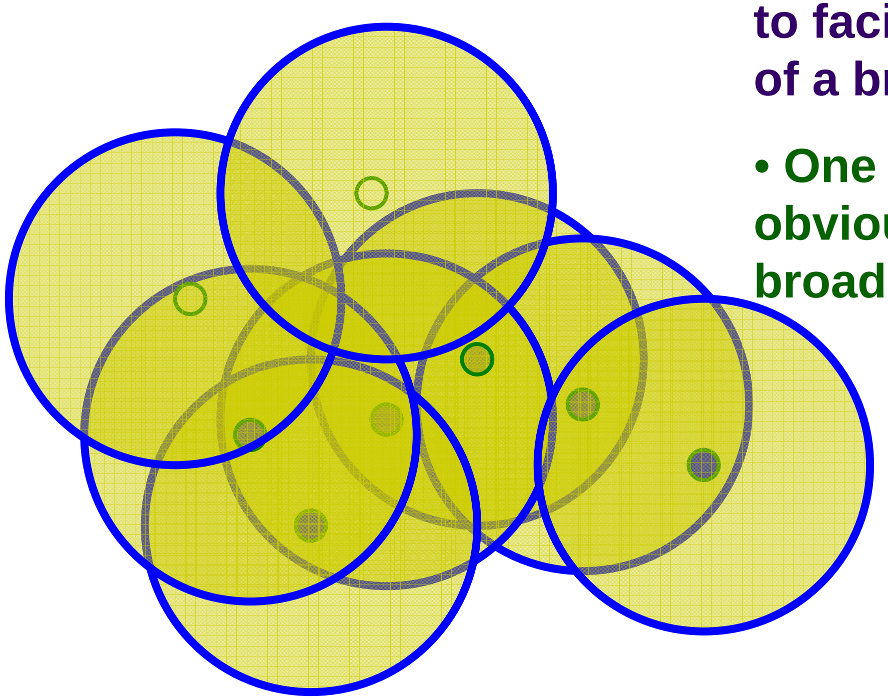
- Broadcasting in a MANET
  - MANET – Mobile Ad Hoc Network
    - No infrastructure
    - Hop by hop
  - Broadcast
    - Graph-related problem
    - Distributed computing problem
    - Resolve many network layer problem

Why MANET need broadcast?



Broadcast Storm

BUT…

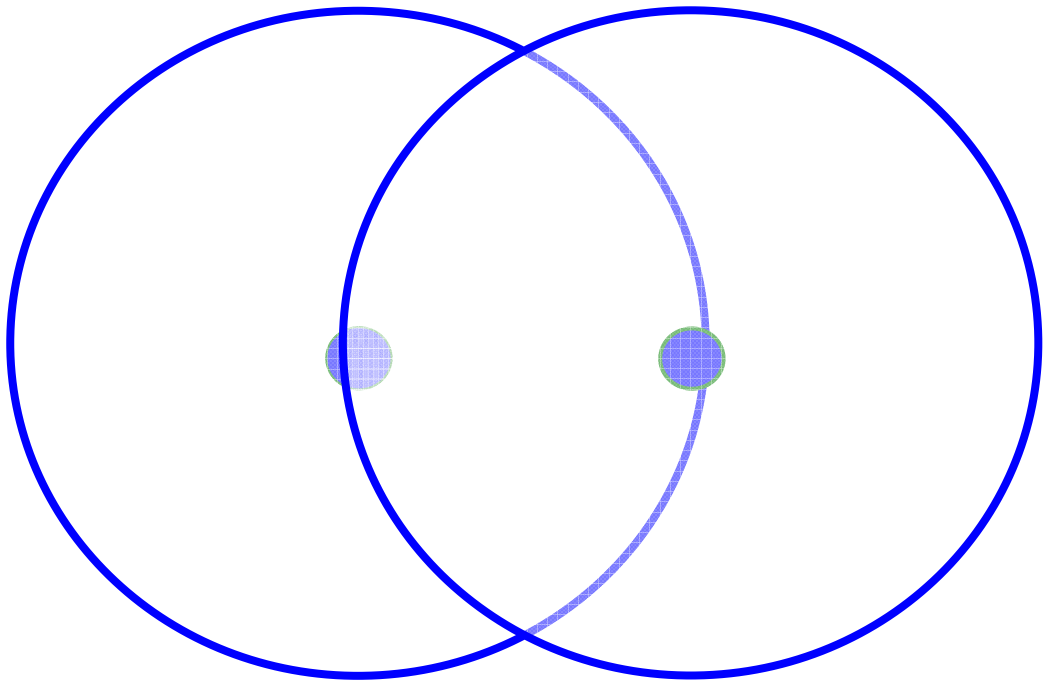


- Synchronization in such a network with mobility is unlikely
- Global network topology information is unavailable to facilitate the scheduling of a broadcast
- One straightforward and obvious solution is broadcasting by flooding

Preliminaries

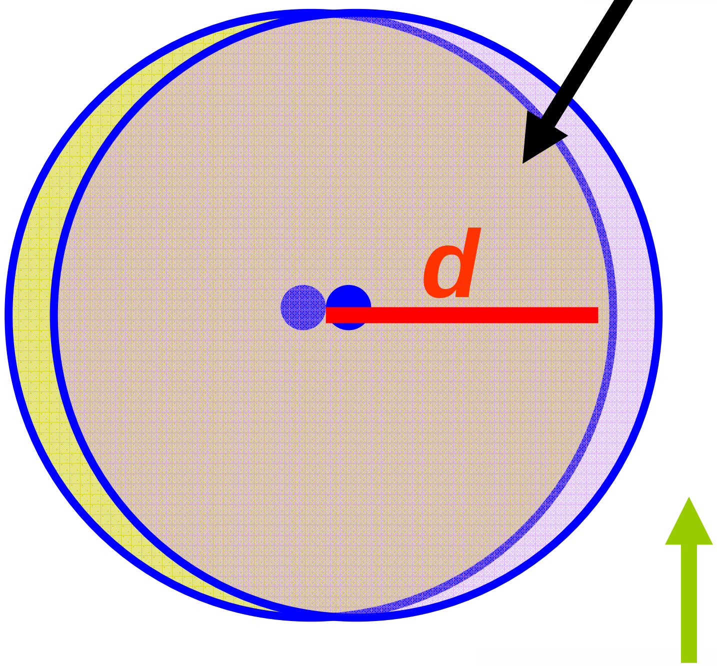
- Broadcasting in a MANET
- Broadcast Storm Caused by Flooding
  - Analysis of Redundant Rebroadcasts
  - Analysis of Contention
  - Analysis of Collision

Analysis of Redundant Rebroadcasts



Analysis of Redundant Rebroadcasts

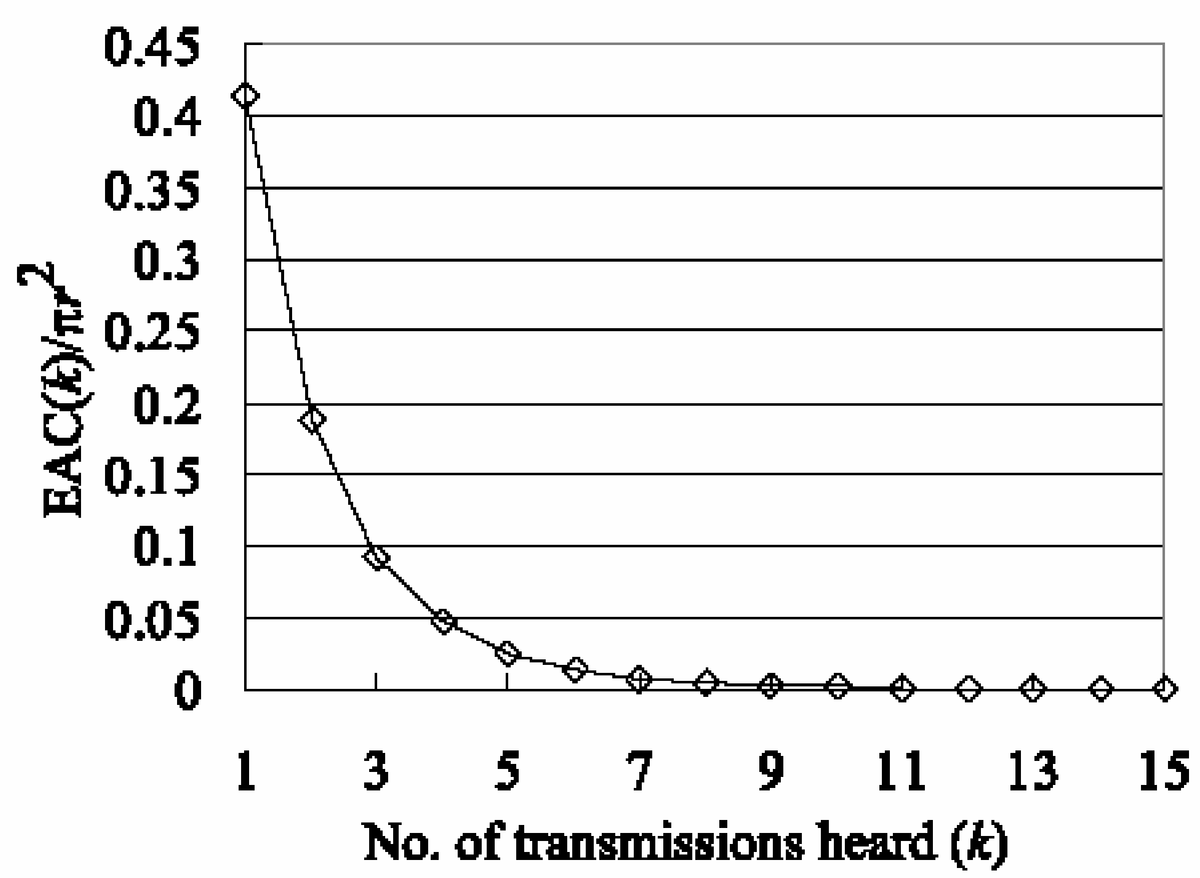
$$\mathrm{INTC}(d) = 4\int_{d/2}^{r} \sqrt{r^2 - x^2}\, dx.$$



$$\pi r^2 - \mathrm{INTC}(r) = r^2\left(\frac{\pi}{3} + \frac{\sqrt{3}}{2}\right) \approx 0.61\pi r^2.$$

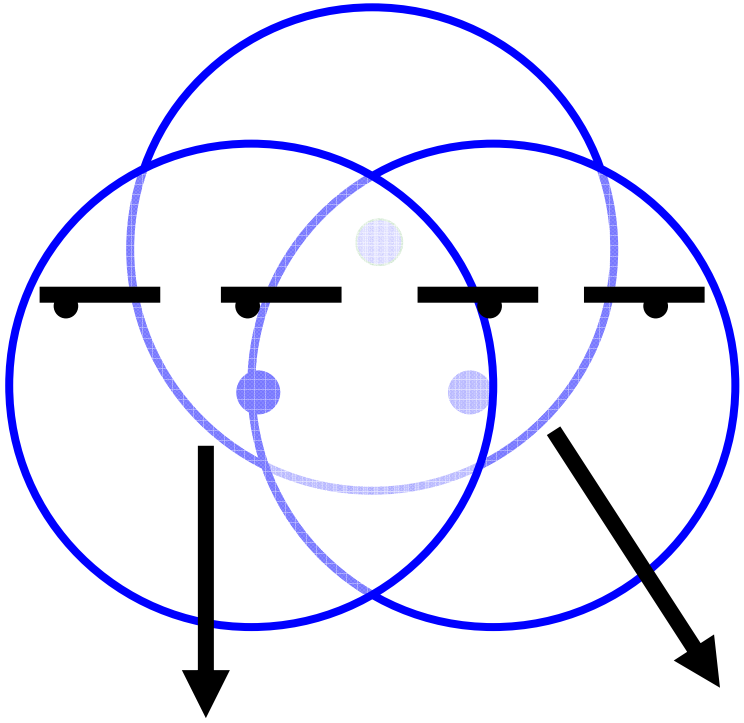
$$\int_0^r \frac{2\pi x \cdot \left[\pi r^2 - \mathrm{INTC}(x)\right]}{\pi r^2}\, dx \approx 0.41\pi r^2.$$

- In general, we would like to know the benefit of a host rebroadcasting a msg. after hearing the msg. *k* times.
- The result can be easily obtained from simulation by randomly generating *k* hosts in a host *X*'s transmission range and calculating the ares covered by *X* excluding those areas already covered by the other k hosts.
- Denote this value by *EAC*(*k*) – ***expected additional coverage after heard the same msg k times***.



When *k* > 4, the expected additional coverage is below 5%

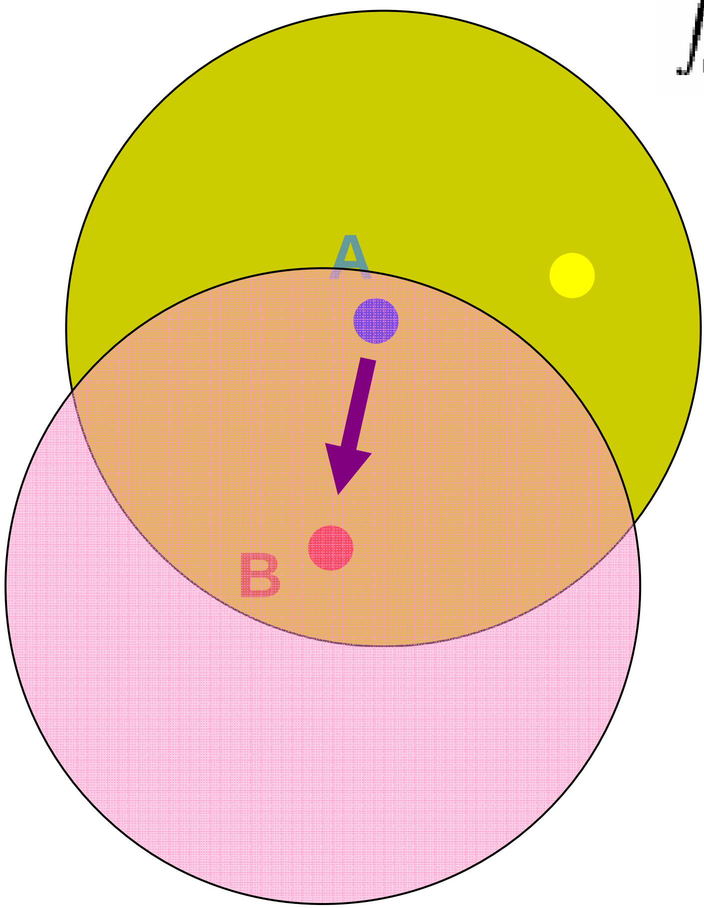
Analysis of Contention

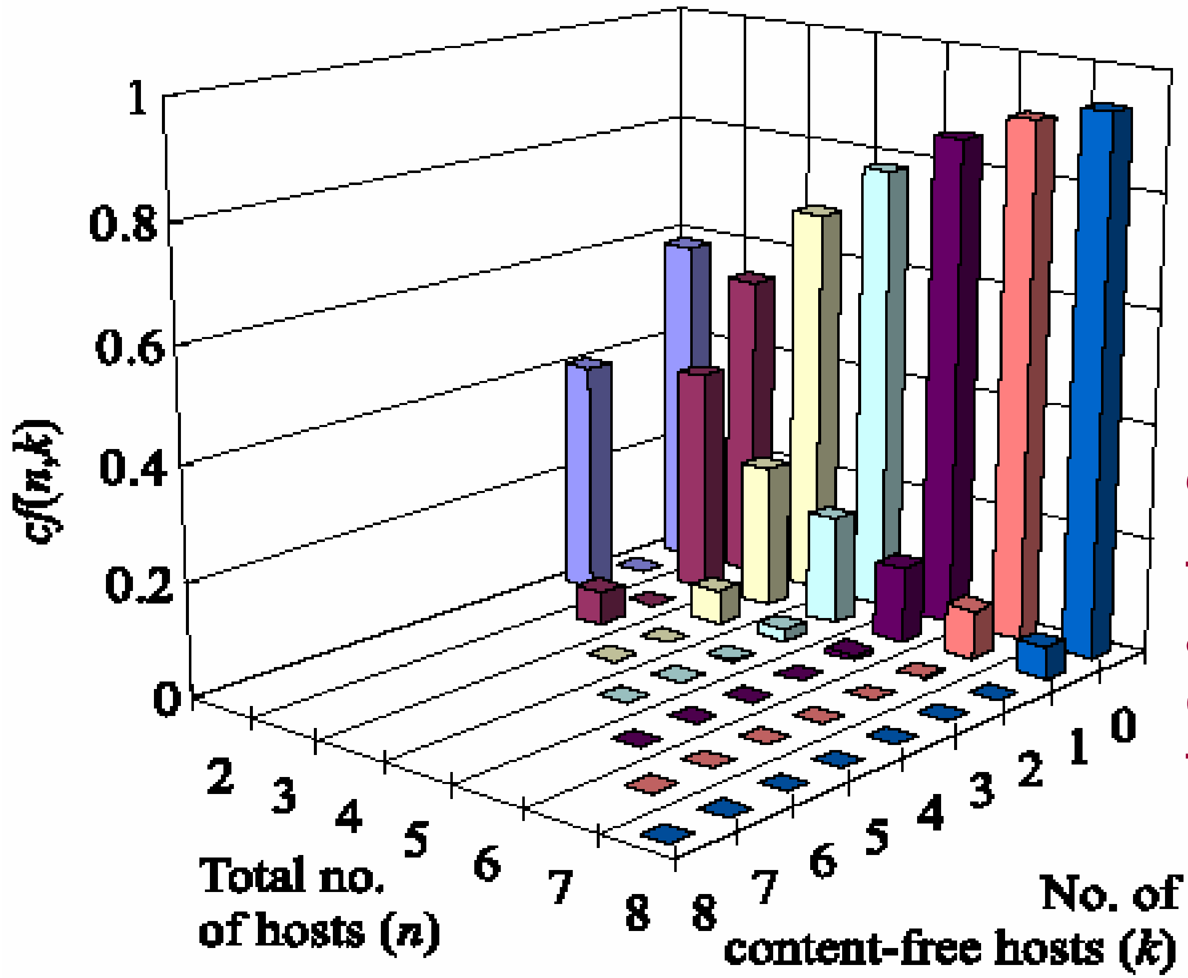


Analysis of Contention

The expected probability of contention

$$\int_0^r \frac{2\pi x \cdot \mathrm{INTC}(x)/(\pi r^2)}{\pi r^2}\, dx \approx 59\%.$$





***cf*(*n*, *k*) :**

the probability that *k* hosts among these *n* hosts experience no contention in their rebroadcasting

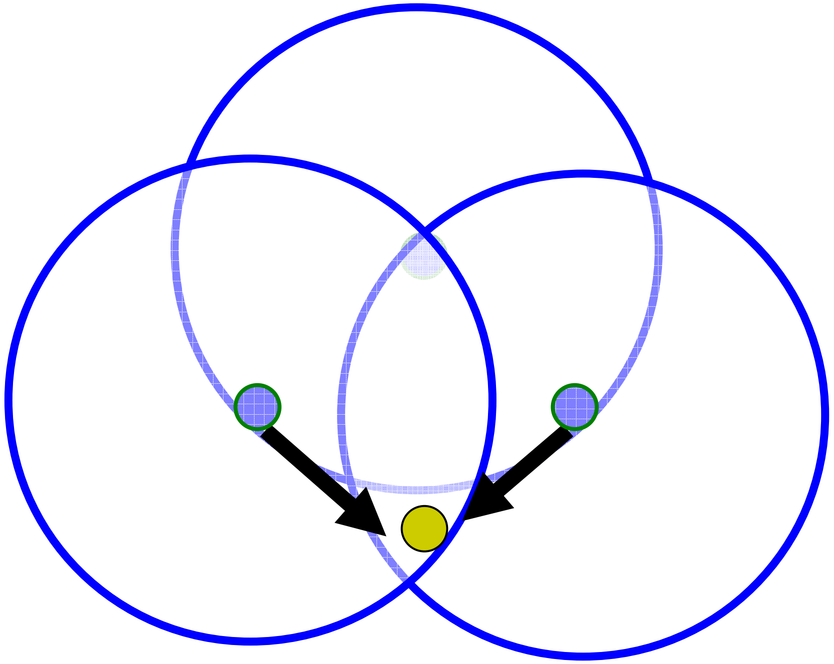
simulation by randomly generation n hosts in A's transmission range

The more crowded the area is, the more serious the contention is.

Analysis of Collision

- **There is no BS or AP in a MANET, we study mainly the behavior under DCF.**
  - CSMA/CA
- **There are several reasons for collisions to happen:**
  - When the surrounding medium of transmitter has been quiet for a long time
  - No RTS/CTS
  - Without *Collision detection* (CD)

Analysis of Collision



Mechanisms to Reduce Redundancy, Contention, and Collision

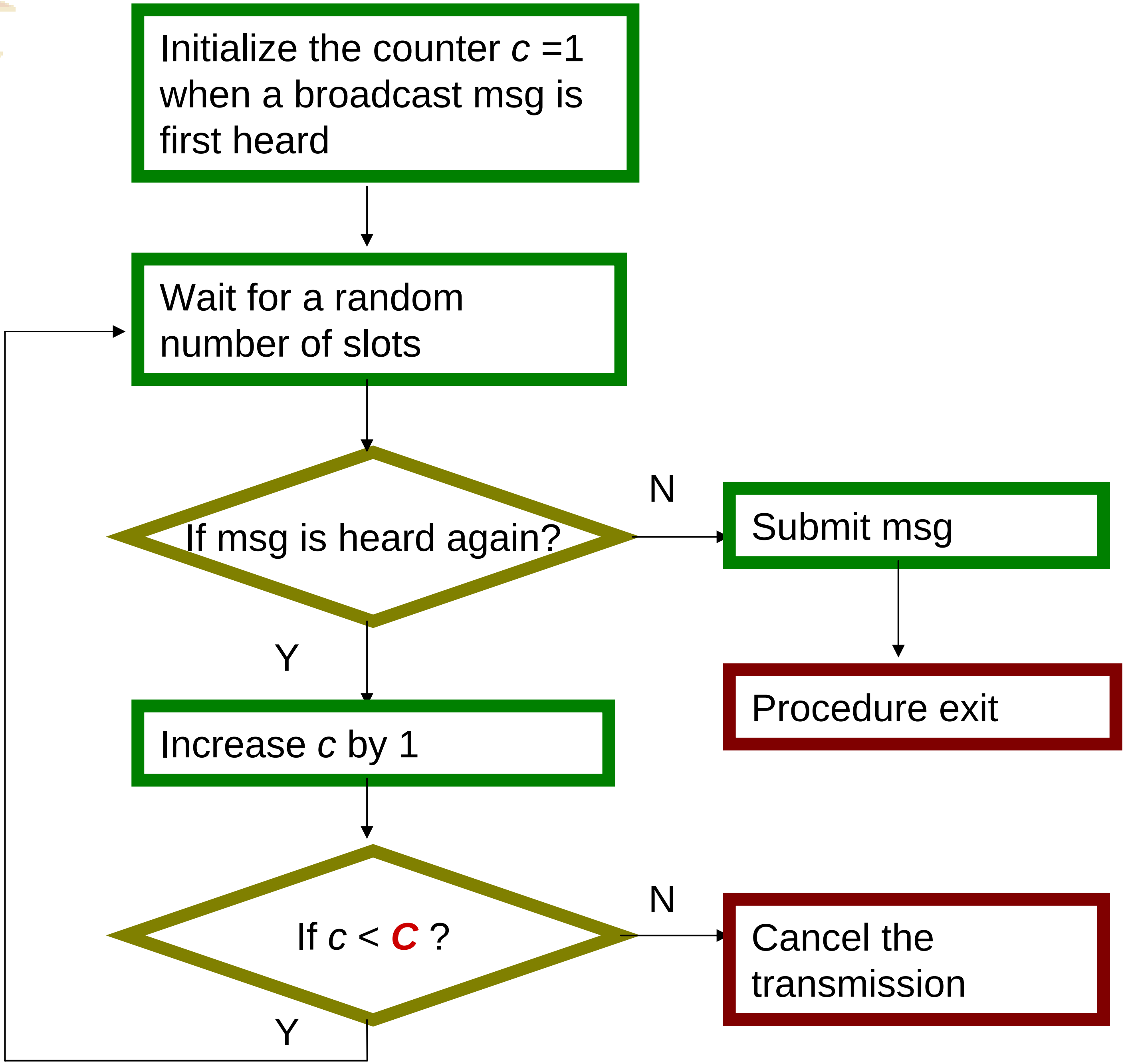
- Probabilistic Scheme
- Counter-Based Scheme
- Distance-Based Scheme
- Location-Based Scheme
- Cluster-Based Scheme

Probabilistic Scheme

- Probabilistic rebroadcasting.
  - On receiving a broadcast message for the first time, a host will rebroadcast it with probability P.
  - When $P = 1$, this scheme is equivlent to flooding.
- Insert a small random delay before the rebroadcasting message.

Counter-Based Scheme

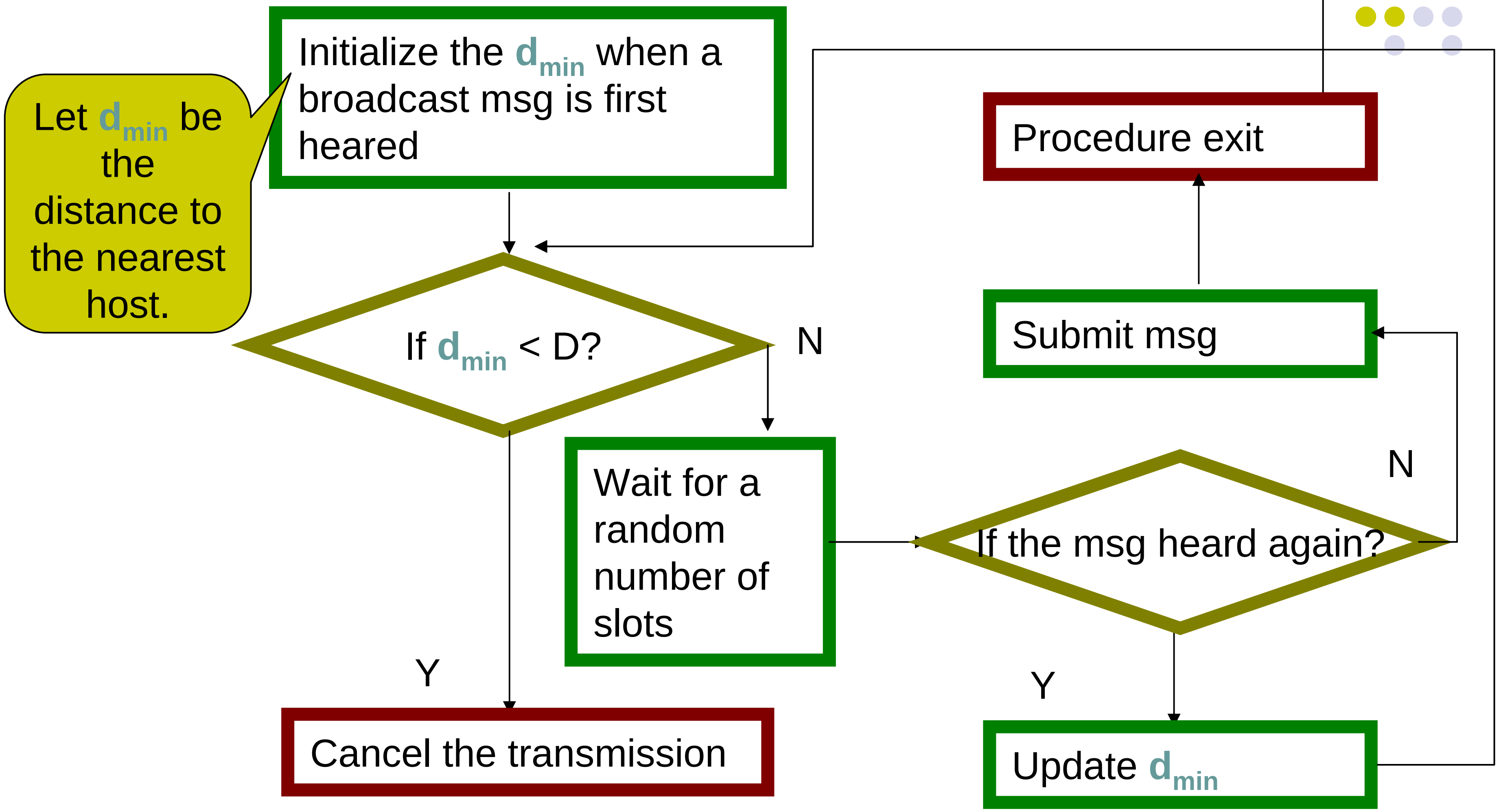
- A host may hear the same message again and again before it actually starts transmitting the message.
- EAC(*k*) – the expected additional coverage after hearing the same msg. *k* times.
  - We can prevent a host from rebroadcasting when the EAC(*k*) of the host's rebroadcast becomes too low.
- A counter threshold **C** is chosen to keep track of **the number of times the broadcast message is received**.


Initialize the counter c =1 when a broadcast msg is first heard
Wait for a random number of slots
If msg is heard again?
N
Submit msg
Procedure exit
Y
Increase c by 1
If c < C ?
N
Cancel the transmission
Y

Distance-Based Scheme

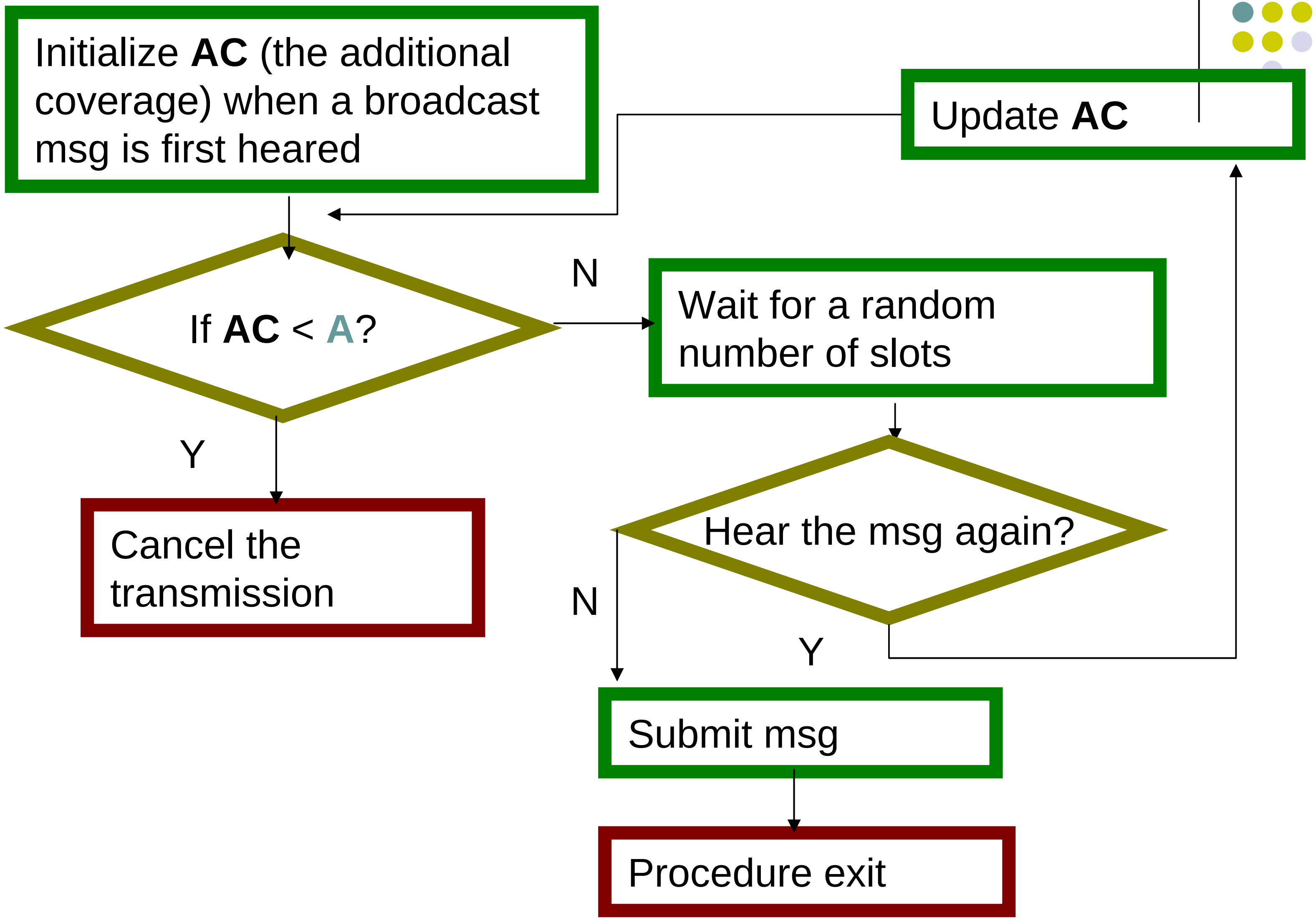
- Use the **relative distance** between hosts to decide whether to drop a rebroadcast or not.
- The distance is shorter, the EAC is smaller.

- A distance threshold **D** is chosen to keep track of **the distance to the nearest host from which the same msg is heard** .
- The distance information is estimated from the signal strength of a received msg.


Let d_{min} be the distance to the nearest host.
Initialize the d_{min} when a broadcast msg is first heared
If d_{min} < D?
N
Y
Wait for a random number of slots
If the msg heard again?
N
Y
Submit msg
Procedure exit
Update d_{min}
Cancel the transmission

Location-Based Scheme

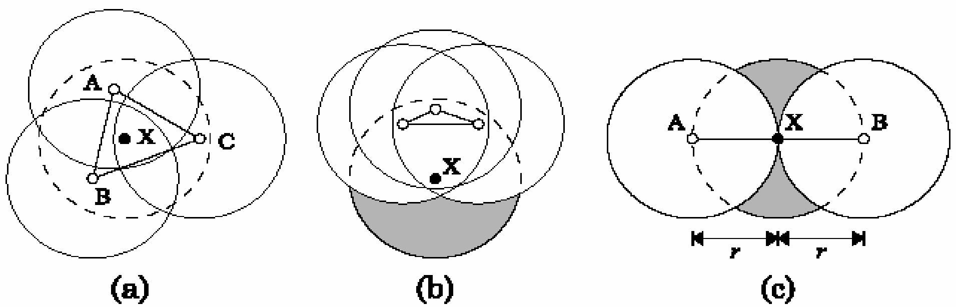
- GPS may used to acquire the location of those broadcasting hosts.
  - Let the receiving host's location be (0,0)
  - Suppose the k transmitting hosts located at(x_1,y_1), $(x_2,y_2),\ldots,(x_k,y_k)$
  - Caculate the additional area that can be covered
- Compare the computed additional coverage to a predefined coverage **A** (0<A<0.61) to determine whether the receiving host should rebroadcast or not.



Initialize **AC** (the additional coverage) when a broadcast msg is first heared
Update **AC**
If **AC** < A?
N
Wait for a random number of slots
Y
Cancel the transmission
Hear the msg again?
N
Y
Submit msg
Procedure exit

Location-Based Scheme

- The previous scheme is too costly.
- An alternative is using a convex polygon to determine whether a broadcast should be carried out or not.



  - Suppose X received msg from A, B and C
  - If X is inside the convex polygon formed by connecting the center of A, B and C, the additional coverage of X's rebroadcast is small or even none.

Location-Based Scheme

- If a host X is in the convex polygon formed by the locations of previous sending hosts, the additional coverage that the host can provide is well below 22%.

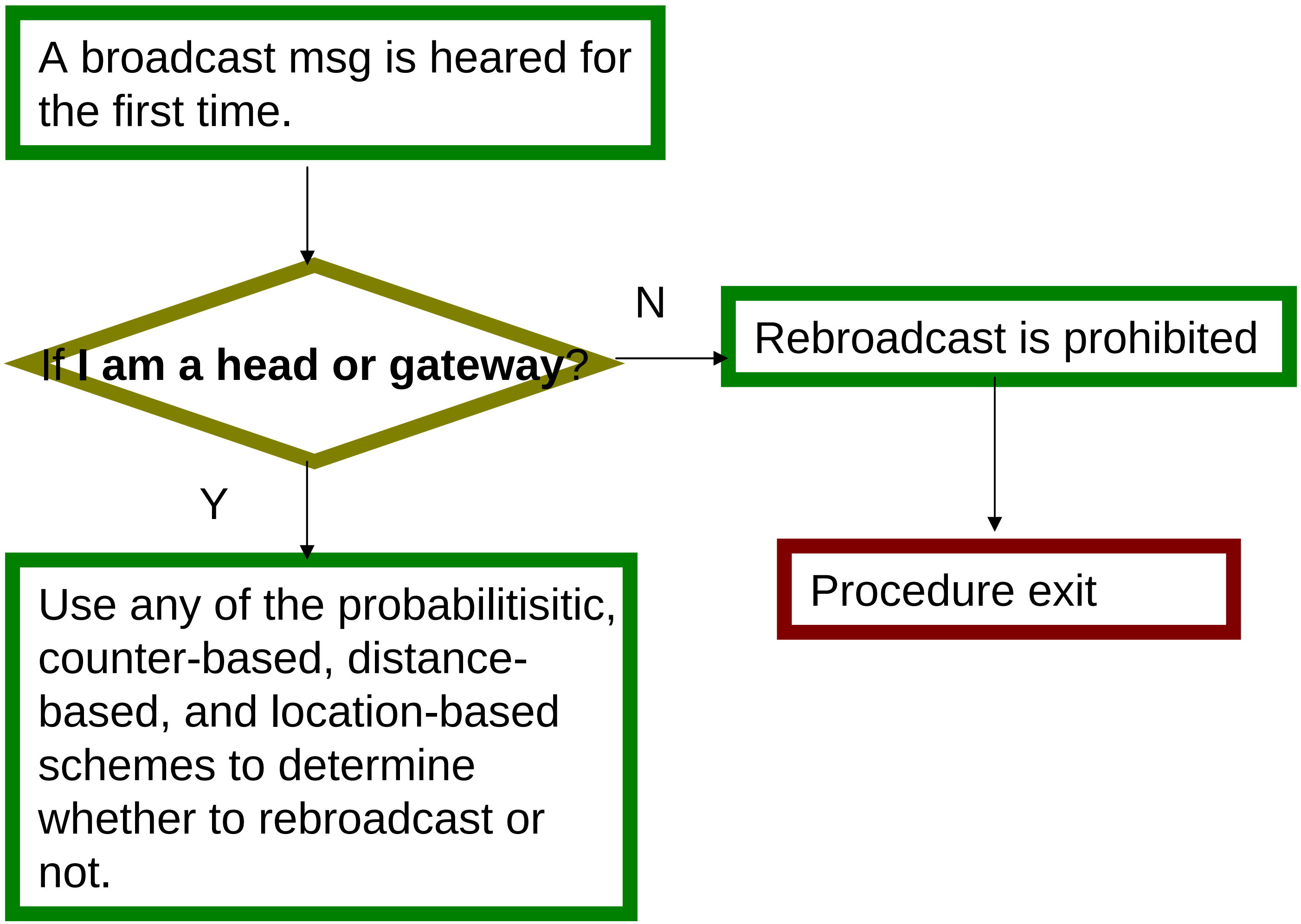
$$\begin{aligned} & 4\left[\int_0^{r/2} \sqrt{r^2 - x^2} \cdot dx - \int_{r/2}^{r} \sqrt{r^2 - x^2} \cdot dx\right] \\ = & \left(\sqrt{3} - \frac{\pi}{3}\right) r^2 \approx 0.22\pi r^2. \end{aligned}$$

Cluster-Based Scheme

- Cluster formation algorithm
  - Each host has a unique ID
  - A host with a local minimal ID will elect itself as a cluster head.
  - This head host together with its neighbor will form a cluster.
  - These neighbor hosts are called member of the cluster.

Cluster-Based Scheme

- Cluster formation protocol:
  - A **head**'s rebroadcast can cover all other hosts in that cluster if its transmission experience no collision.
  - **Gateway** hosts should take the reponsibility to propogate the broadcast msg to hosts in other clusters.
  - There is no need for a non-gateway member to rebroadcast the msg.


A broadcast msg is heared for the first time.
If I am a head or gateway?
N
Rebroadcast is prohibited
Y
Use any of the probabilitisitic, counter-based, distance-based, and location-based schemes to determine whether to rebroadcast or not.
Procedure exit

Information about Simulation

- The fixed parameters in the simulations are
  - transmission radius (500 meters)
  - the broadcast packet size (280 bytes)
  - the DSSS physical layer timing (PLCP overhead, slot time, inter-frame separations, backoff window sizing, as suggested in IEEE 801.11)

Information about Simulation

- map size – 1×1, 3×3, 5×5, 7×7, 9×9, 11×11 units (a unit is of length 500 meters)
- 100 mobile hosts.
- initially, hosts are randomly distributed over a map.
- to simulate host mobility, each host will roam around randomly in the map during the simulation.

Information about Simulation

- The roaming pattern of a host is simulated by generating a series of **turns**.
- In each **turn**, a **direction**, a **velocity**, and a **time interval** are generated.
- the **direction** is uniformly distributed from 0°~360°
- the **time interval** uniformly distributed from 1 to 100 seconds
- the **velocity** is randomly chosen
  - from 0 to 10 km/hr in a 1×1 map
  - from 0 to 30 km/hr in a 3×3 map
  - from 0 to 50 km/hr in a 5×5 map
  - from 0 to 70 km/hr in a 7×7 map

Information about Simulation

- the arrival rate for the whole map is one broadcast request per second.
- the broadcasting host is randomly picked for each request.
- a small random delay ranging from 0 to 31 slots is inserted before each attempt at rebroadcasting.

Information about Simulation

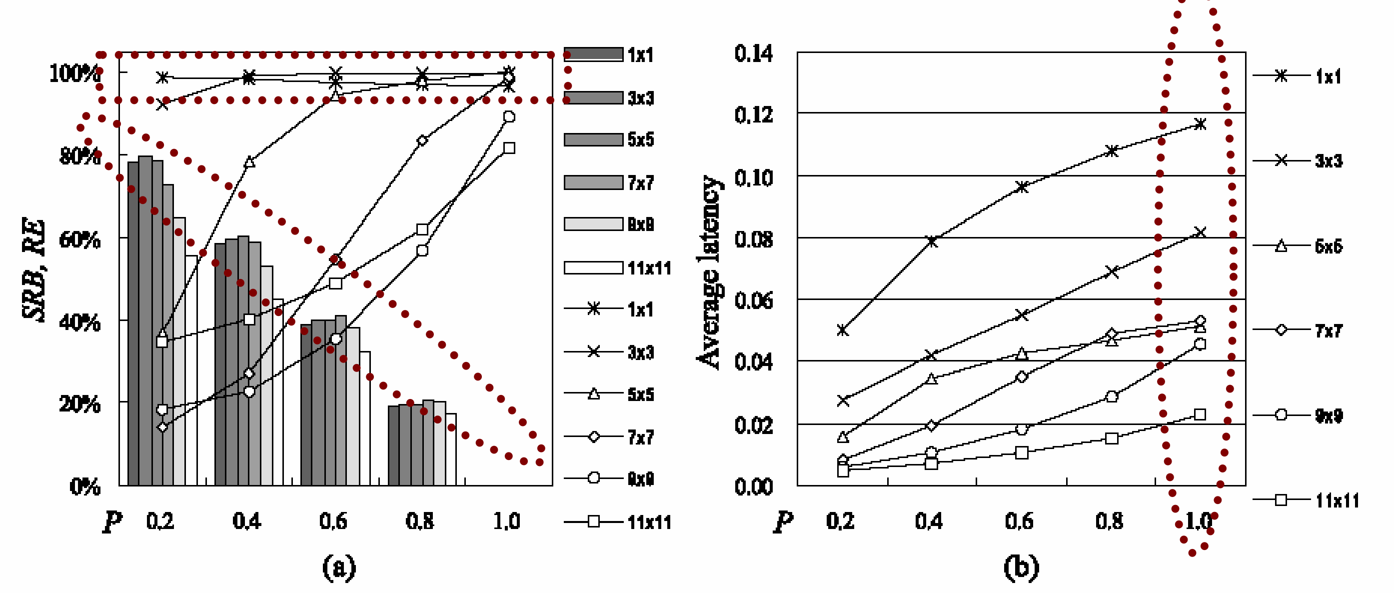
- The performance metrics to be observed are:
  - REachability (***RE***)
    - The number of mobile hosts receiving the broadcast msg divided by the total number of mobile hosts that are reachable, directly or indirectly, from the source host.
  - Saved ReBroadcast (***SRB***)
    - $(r-t)/r$, where r is the number of hosts receiving the broadcast message, and t is the number of hosts that actually transmitted the message.
  - Average Latency
    - The interval from the time the broadcast was initiated to the time the last host finished its rebroadcasting.

Performance Simulation

- Performance of the Probabilistic, Counter-Based, Distance-Based, Location-Based, and Cluster-Based Schemes
- The Relationship between ***RE*** and ***SRB***
- The Effect of Load (arrival rate)

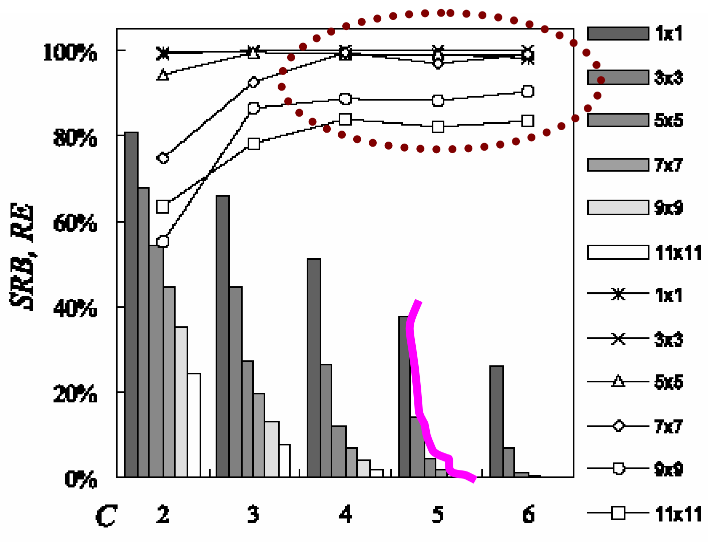
Performance of the Probabilistic Scheme

1. Fig.8(a) In a small map, a small ***P*** is sufficient to achieve high ***RE***.
2. Fig.8(a) The amount of SRB decreases, roughly proportionally to (1-***P***), as ***P*** increase.
3. Fig.8(b) MANET with sparser hosts tends to complete broadcasting more quickly. (collision and contention)

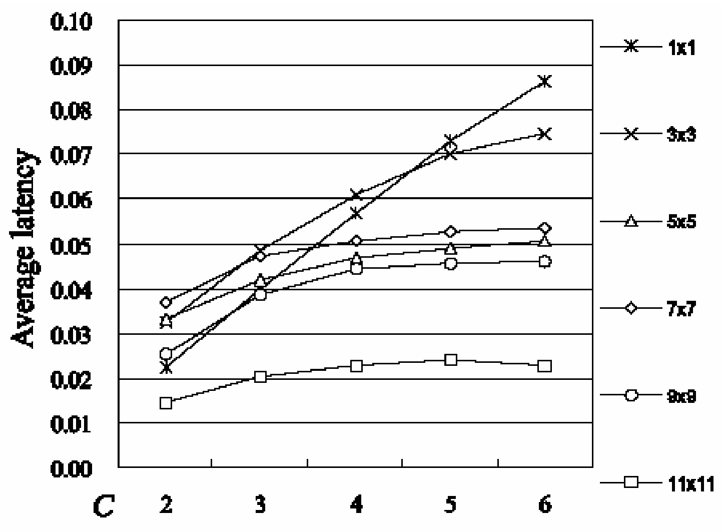


Performance of Counter-Based Scheme

- Fig.9(a) The ***RE*** in fact reaches about the same level when the counter threshold ***C***>=3.
- Fig.9(a) Various levels of SRB can be obtained over the flooding scheme, depending in the density of hosts in a map.
- Fig.9(a) When the map is very sparse(11×11) and C is very large, the amount of saving decreases sharply.



(a)

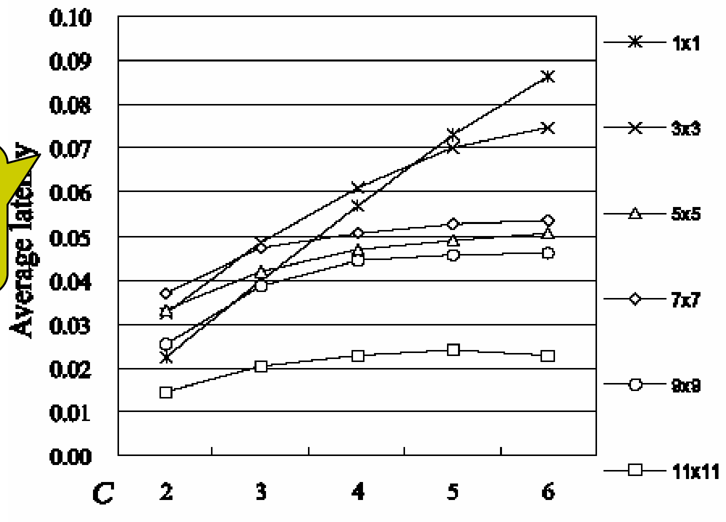


(b)

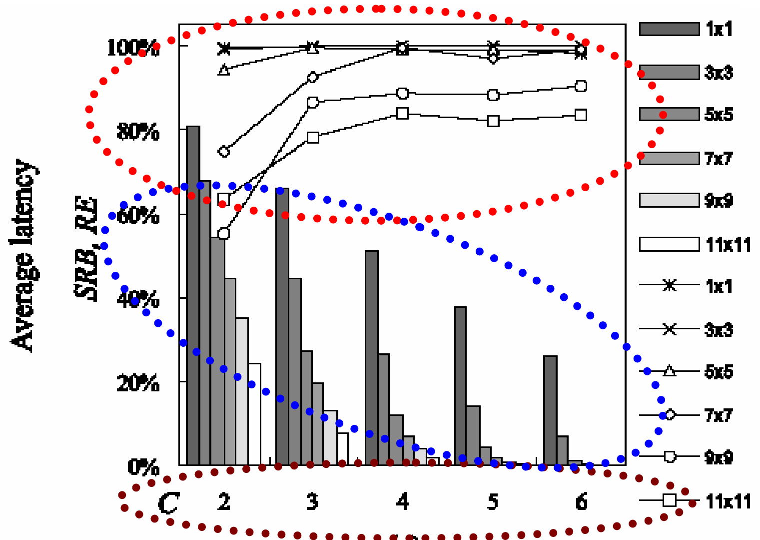
Performance of Distance-Based Scheme

- When D is small enough, the network's behavior is very close to one using flooding.
- By comparing Fig.9(a) and Fig.10(a), we observed that distance-based scheme can provide better ***RE***, but worse ***SRB***.
- Its **Latency** is higher because a host may heard a msg many times but still decide to rebroadcast it because none of the transmission distances are below D.

Counter-based



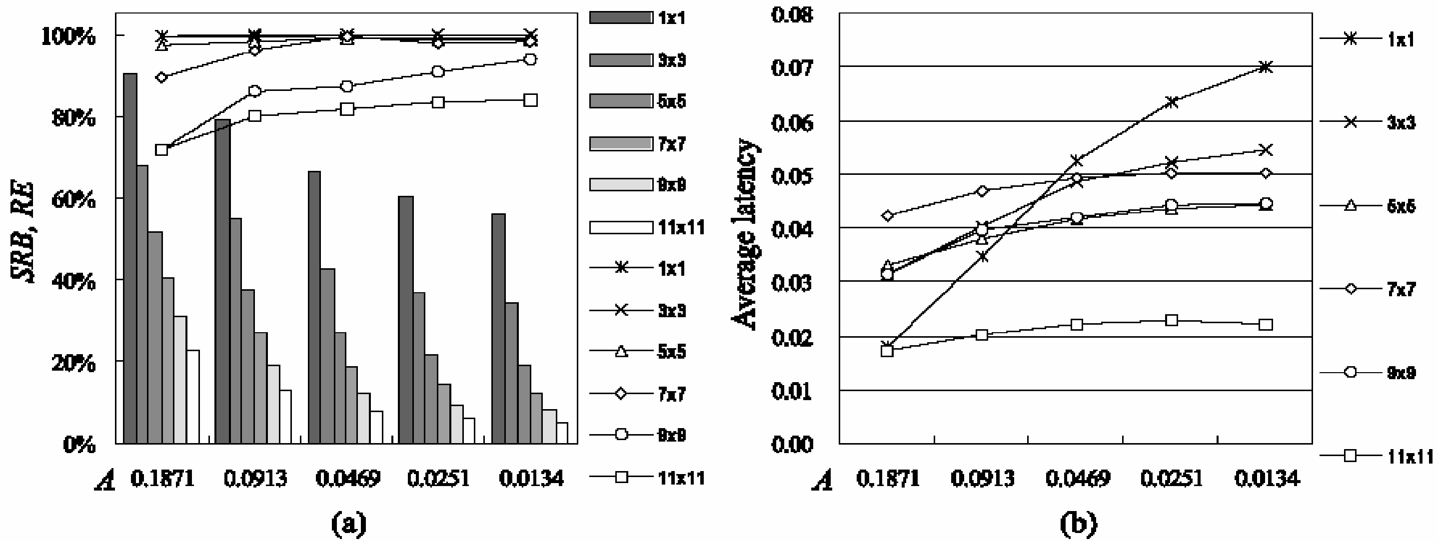
(b)



(a)

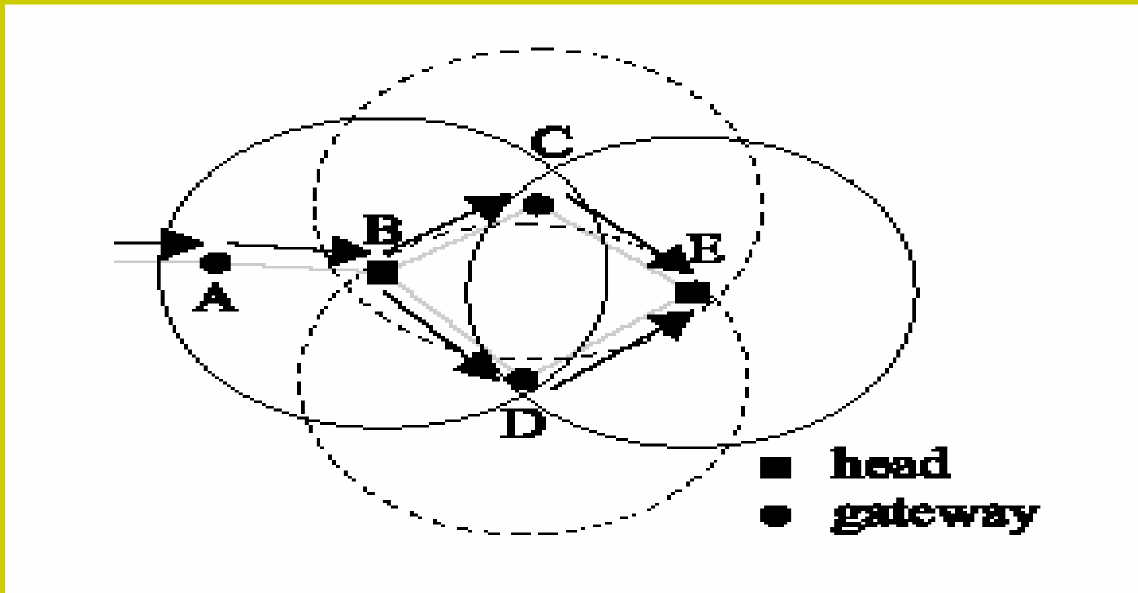
Performance of Location-Based Scheme

- Fig.11(a) By comparing with the distance-based and counter-based schemes, the location-based scheme has the best RE and SRB.
- Fig.11(a) Because the location-based scheme use the most accurate information to determine the additional coverage.



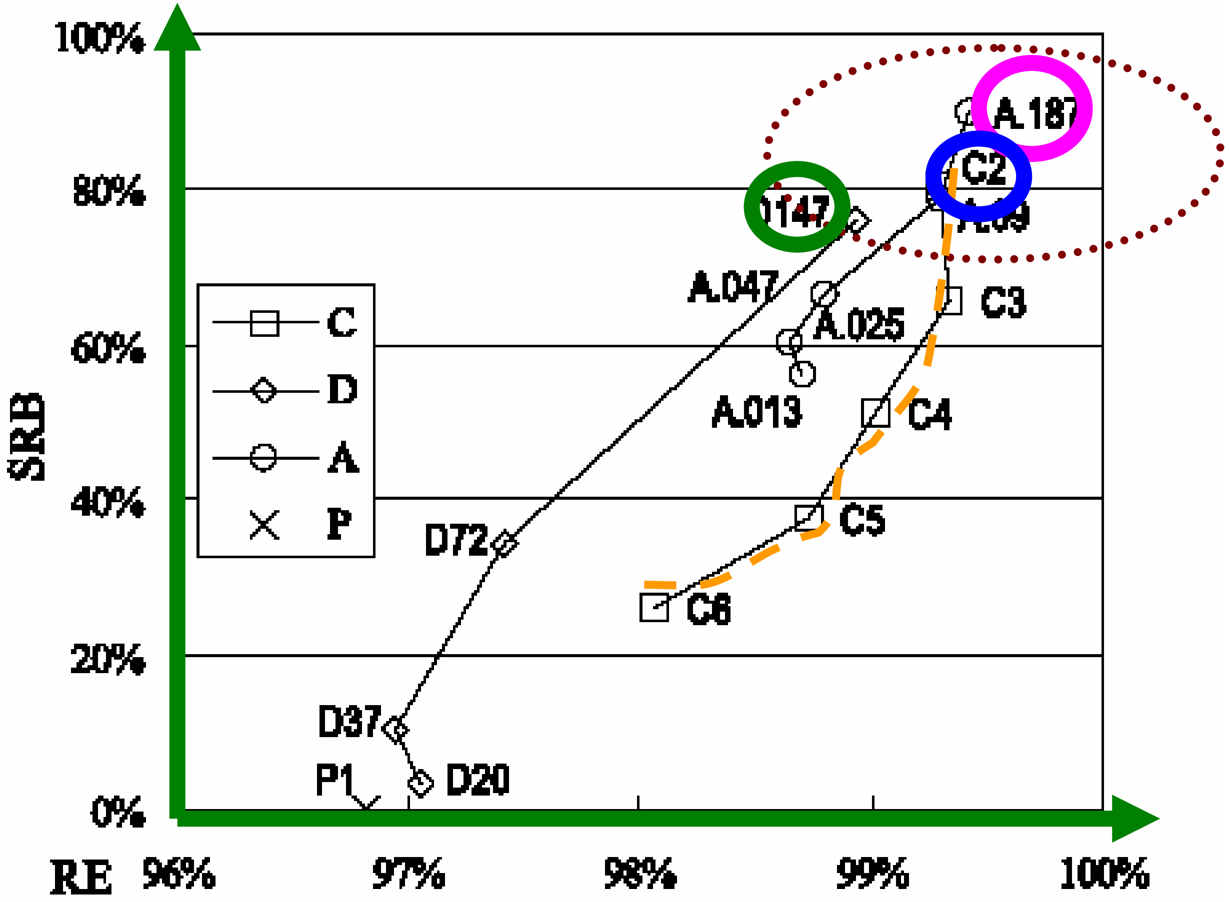
Performance of Cluster-Based Scheme

- Fig.12(a) Unfortunately, the *RE* is unacceptable at sparser areas.
  - **This is probability because when the number of hosts participating in rebroadcasting is reduced, the collision caused by the hidden terminal problem will significantly reduce the chance of successful transmission.**



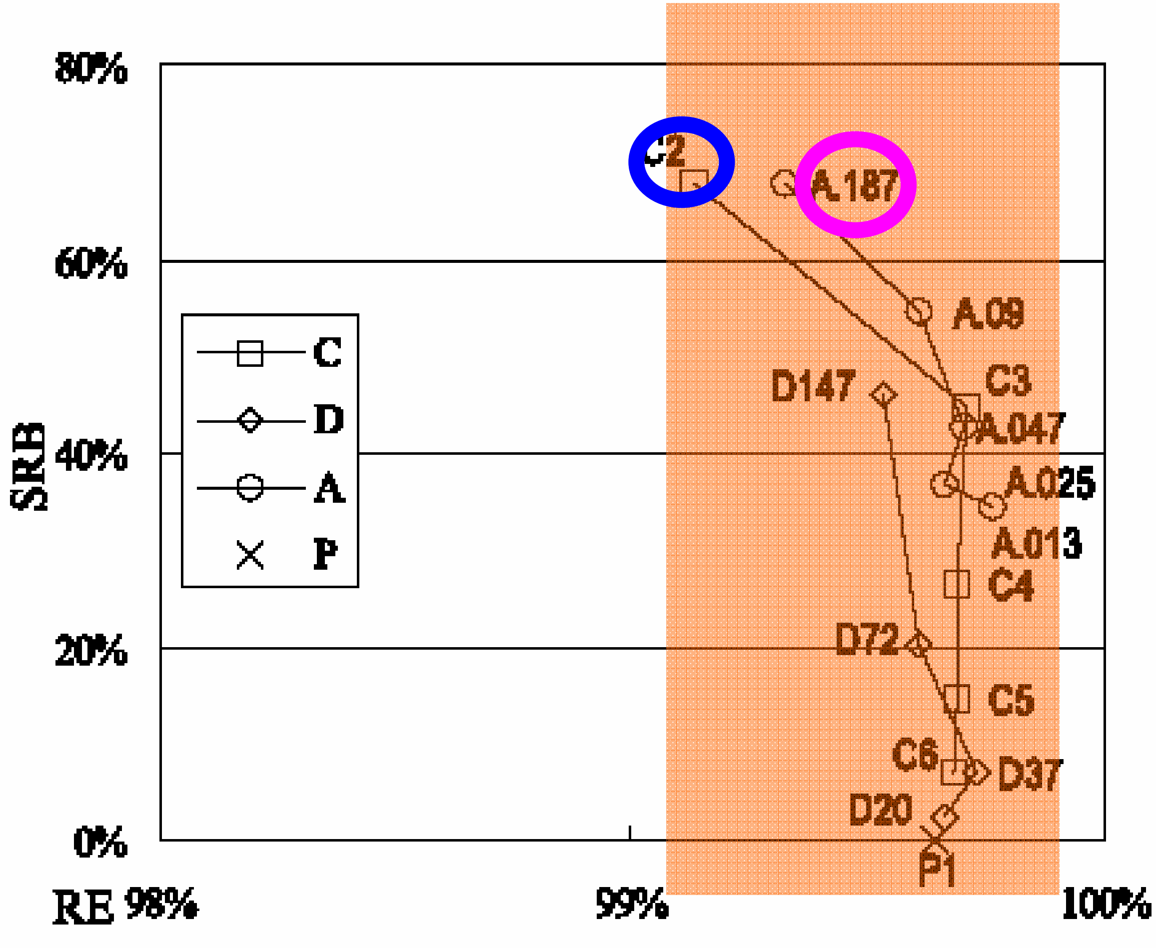
1x1
3x3
5x5
7x7
9x9
11x11

The relationship between *RE* and *SRB*



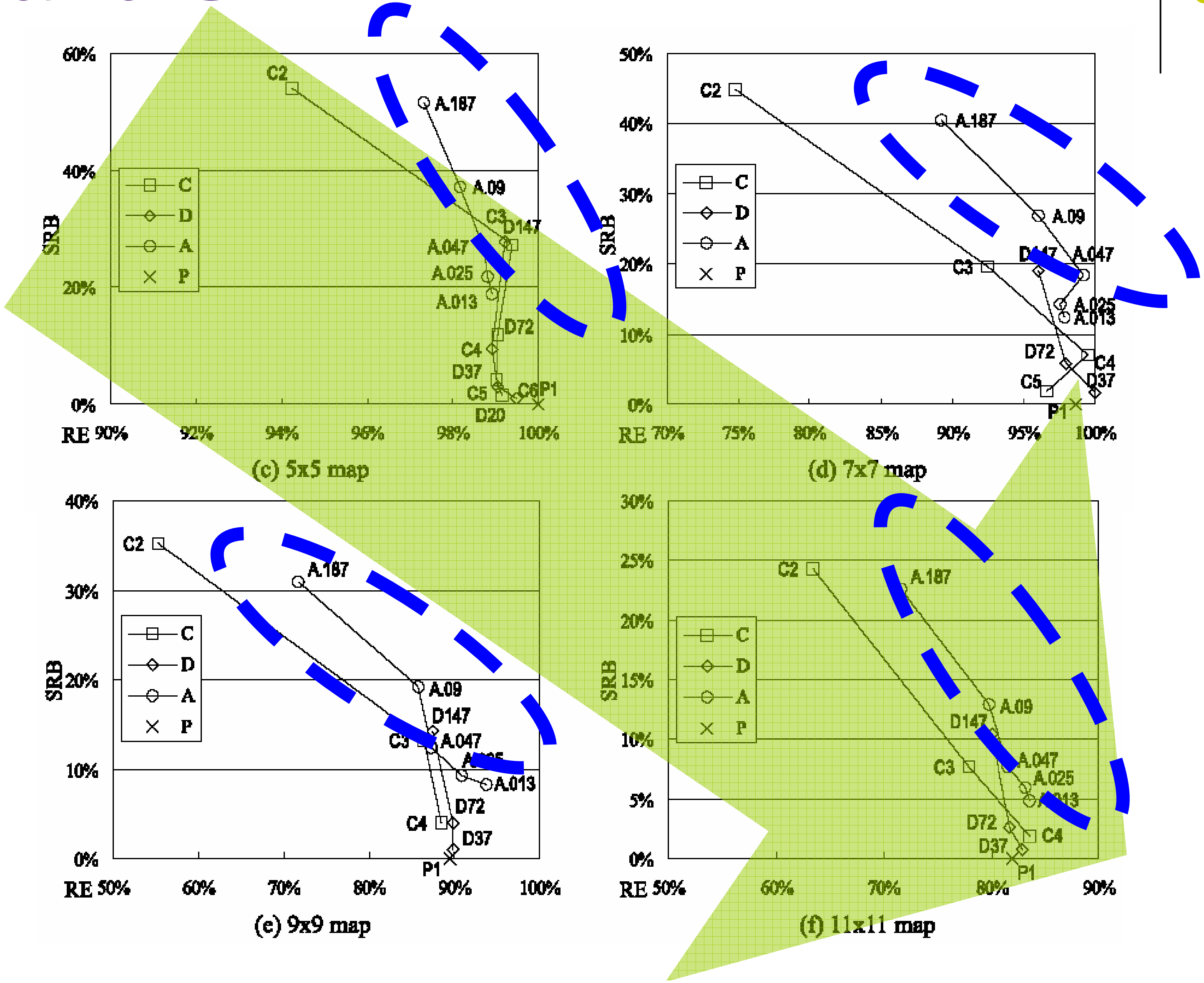
(a) 1x1 map

The relationship between *RE* and *SRB*



(b) 3x3 map

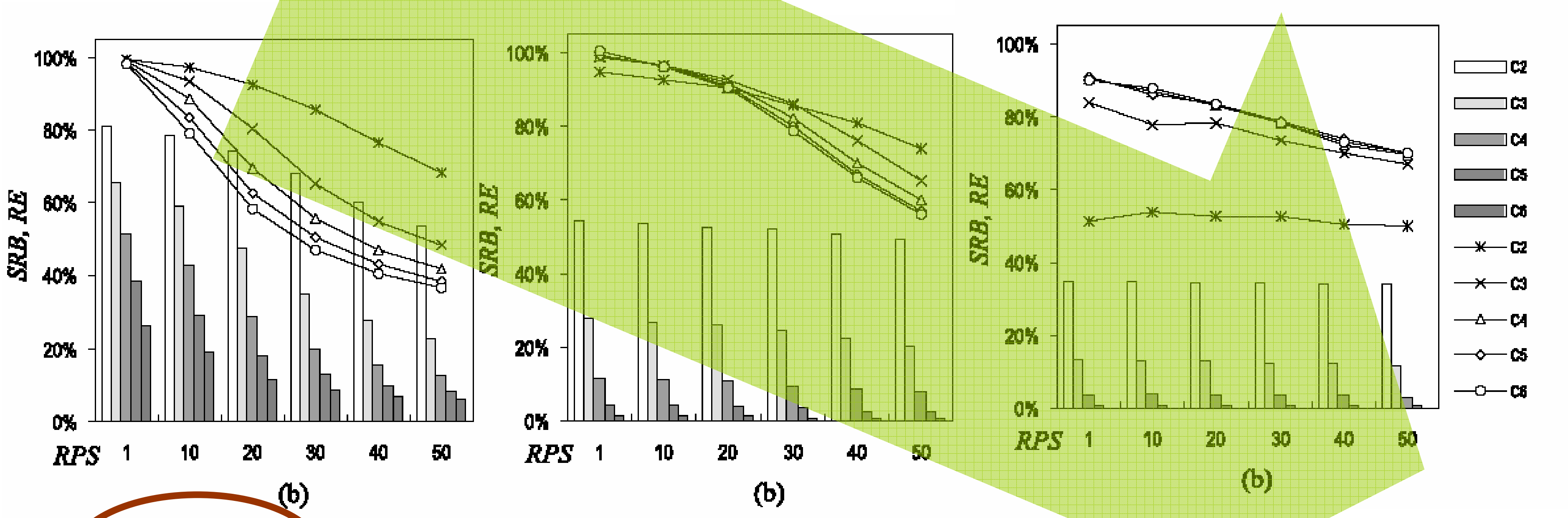
The relationship between *RE* and *SRB*



The Effect of Load

Larger RPS cause more contention and collision

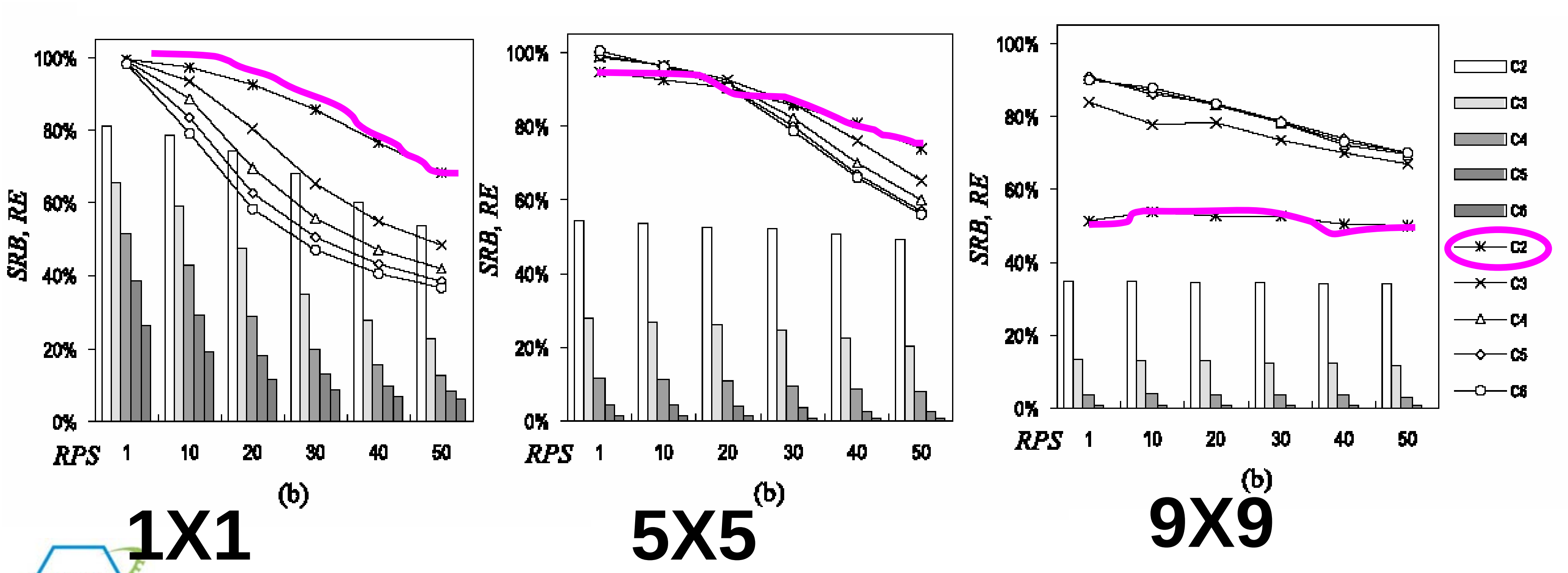
- Counter-Based scheme
- With different arrival rate:



1X1 **5X5** **9X9**

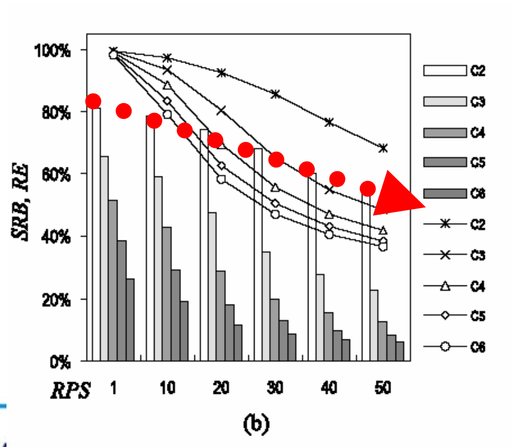
The Effect of Load

The larger map can distribute the broadcast requests to larger physical areas, and thus lower the severity of contention and collision caused by rebroadcasting.

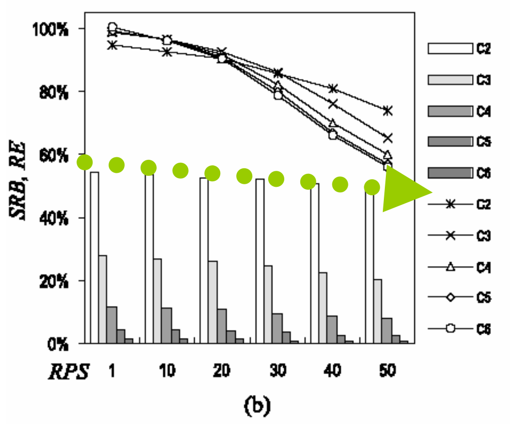


The Effect of Load

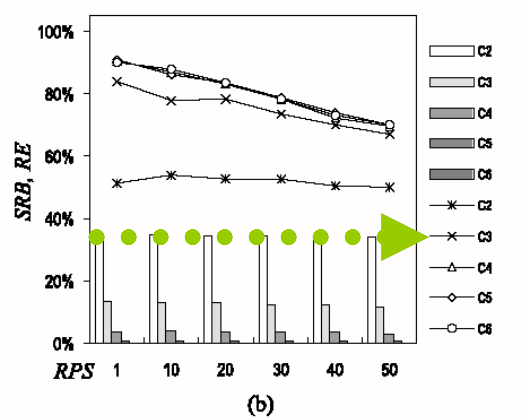
- The SRB will decrease as the load increases in a 1X1 map, this means that there are more hosts trying to help rebroadcast the broadcast packets.
- But the level of RE keeps on going down as load increases.
- Fortunately, in larger maps the SRB remains almost unchanged as load increases.



1X1



5X5



9X9

Conclusions

- A problem storm problem is analysis and investigated