國立交通大學

資訊科學系

碩士論文

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中文摘要

在無線隨意網路中(MANETs), 廣播機制是一個常見的功能,用以提供各種網路服務，例如：路由路徑搜尋、資源搜索…等等。然而，沒有適當的控制機制—即所謂的氾濫廣播法，會導致嚴重的重送、競爭以及碰撞問題。這些問題被定義為「廣播風暴問題」，已經有許多研究提出了解決的方法，但是大部分的方法在網路涵蓋能力(Reachability)以及節省重送效能(Saved Rebroadcast)上無法取得平衡。在計數方法(counter-based scheme)中，每個無線節點根據鄰近區域的節點密度決定是否重送，然而，這個方法並沒有將每個重送點之間的相對距離的觀念加入考慮，我們提出了幾個解決問題的方法，DISCOUNT 以及 DIS_RAD (DIStinct RAD)演算法，前者將技術方法以及距離感測方法作了一個良好的混合，將距離觀念加入計數方法中，我們演算法的基本觀念是，外圈的應該有較高的重送機率，因為他們有較好的額外覆蓋面積(EAC)，在此演算法中，我們利用距離門檻 (distance threshold)來區別內圈點及外圈點，並採用不同的隨機延遲時間(RAD)，並針對內圈點及外圈點此用不同的隨機延遲時間，使得外圈點有較短的延遲時間，基於此種改變，我們推導出了內圈點及外圈點兩種不同的重送機率，分析的結果顯示我們的演算法的確可對外圈點提供較高的重送機率，內圈點提供較低的重送機率。模擬結果描述了 DIS_RAD 的確會提供比技術方法有好的

多的效能，此結果也與我們的機率分析模型箱符合。最重要的是，我們的方法不管在任何不同的網路密度皆可提供良好的網路涵蓋能力以及節省重送效能。

關鍵字：行動隨意網路、隨機延遲時間、廣播風暴問題、計數方法。

Distance-Aware Probability-Based Broadcast Schemes for Mobile Ad Hoc Networks

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Abstract

In mobile ad hoc networks (MANETs), broadcasting is a common operation for providing network functions, such as route discovery and source paging. However, an uncontrolled broadcast, which is also called blind flooding, is inefficient and may lead to heavy redundancies, contentions and collisions, and is commonly referred to as a “broadcast storm” [1]. Although this problem has been addressed extensively, most studies suffer with respect to balance between coverage performance and rebroadcasting efficiency. In a counter-based scheme, a mobile node determines the rebroadcast probability based on the node density in its neighborhood, but does not include the distance concepts which helps improve the Expected Additional Coverage (EAC) [1]. This investigation proposes several algorithms to solve broadcast storm problem. The DISCOUNT scheme combines both DIStance-based and COUNTter-based schemes. The DIS_RAD distinguishes different Random Assessment Delays (RAD) from border nodes to interior ones. The DISCOUNT-RS further improve the performance of the mentioned algorithms. The basic idea of these algorithms is that give nodes closer to the border should have a higher rebroadcast probability since they create better Expected Additional Coverage (EAC) values. Here, a distance threshold is adopted to distinguish between interior and border nodes. Two distinct RADs are applied to the border and interior nodes, with the border nodes having shorter RADs than the interior nodes. Based on this change, the two rebroadcast probabilities are derived for the nodes located at the border annulus and those located at the interior circle. The analytical results indicate that the proposed scheme indeed provides a higher rebroadcast probability for border nodes and a lower rebroadcast probability for interior nodes compared with the counter-based scheme. The simulation results demonstrate that the proposed "DIS_RAD" scheme works much better than the counter-based scheme. The probability analysis model also confirms the validity of the simulation results. The most important, the proposed scheme can keep good balance between reachability and rebroadcast efficiency in various network densities. Therefore, the dynamic adjust counter threshold according to network densities is not necessary.

Keywords: Broadcast; Mobile Ad Hoc Networks (MANETs); Random Assessment Delay (RAD); broadcast storm; Expected Additional Coverage (EAC).

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Chapter 1: Introduction

Mobile Ad Hoc networks (MANETs) are wireless networks with no fixed infrastructure. Each node in the network may function as a router if it needs to forward packets for the node pairs that cannot communicate directly. In such networks, fundamental network services such as resource discovery and route construction are achieved by broadcast. Since resources such as bandwidth, energy and channel are very precious in MANETs, requests must be served at the lowest possible cost. In a simple broadcast method, called “blind flooding”, every node in the MANET rebroadcasts the received message exactly once. However, this scheme leads to “broadcast storm problem” which suffers redundant rebroadcasts, channel contentions, and collisions.

Since the broadcast storm problem is that too many unnecessary packets flood the network, some approaches have been proposed to solve this problem, which are described in the following section. Furthermore, the wireless technology sets a trend toward dynamic environment; therefore, the promising solution should adapt to a turbulent topology.

A counter-based scheme is a simple and distributed approach that determines nodes’ rebroadcast probability by the node density within area of transmission range. The proposed approach operates as follows. When a node receives a new rebroadcast request, a Random Assessment Delay (RAD) is initiated before making the rebroadcast decision. To obtain the current neighborhood density, each node counts the number of duplicated rebroadcast requests received during the RAD period. After a node’s RAD expires, the node rebroadcasts the request if its counter does not exceed the preset counter threshold; otherwise, the request is dropped. Generally, the transmission area of nodes in dense networks overlaps considerably. Thus, the reachability performance is not diminished if some nodes do not rebroadcast. Therefore, a lower counter threshold should be specified in dense networks to save rebroadcasts. Sparse networks have a much lower overlapped area. Thus, more nodes should rebroadcast to maintain a good reachability. Consequently, a sufficiently high counter threshold should be specified in sparse networks. To maintain good balance between reachability and rebroadcast saving, the counter threshold should be able to adjust dynamically according to node density of the networks [4]. However, a broadcast algorithm with a dynamic counter threshold is difficult to implement for diverse network topologies. Moreover, a node rebroadcast probability would not be distinguished according to the size of its EAC in the counter-based scheme. Consequently, more rebroadcasts are needed to ensure an equivalent reachability performance. Figure 1 illustrates this case. Node S initiates a broadcast request. Node A is located close to the source node and has a small EAC. Nodes B and C are far from the source node and have large EAC values. The shaded area depicts the additional coverage from the source node. Clearly, node A does not need to rebroadcast if node B and C both decide to rebroadcast, since the additional coverage of node A is covered by nodes B and C. In the counter-based scheme, node A may rebroadcast before nodes B and C because the RADs are given at random.

The above example indicates that the efficiency of each rebroadcast can be improved if the nodes that cover larger additional coverage (nodes B and C in this example) have an opportunity to determine whether to rebroadcast before the nodes that cover less additional coverage (ex. node A). Therefore, this study proposes a scheme named Distinct RAD or Distance RAD (DIS_RAD), which adds the distance concept to a counter-based scheme. A distance threshold (D_{th}) is introduced to segregate border nodes from interior nodes. In DIS_RAD, the border nodes initiate a short RAD (SRAD), and interior nodes initiate a long RAD (LRAD), where LRAD is longer than SRAD. Therefore, the nodes at the border of the transmission range of source determine whether to rebroadcast before the interior nodes broadcast. The simulation results demonstrate that the proposed DIS_RAD outperforms the counter-based scheme in all aspects. Furthermore, the proposed scheme can keep good balance between reachability and rebroadcast efficiency in various network densities. Therefore, the dynamic adjust counter threshold according to network densities is not necessary. The proposed algorithm was also analyzed using the probability model. The broadcast probability was divided into two parts: broadcast probability of interior nodes (Pi) and border nodes (Pb), depending on whether the node is located at the border area or in the inner area.

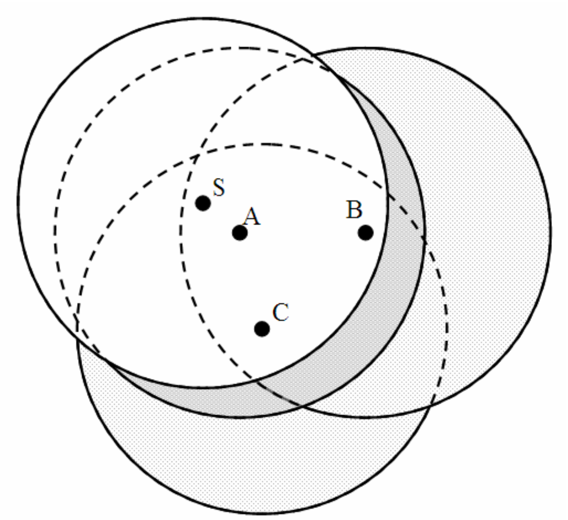

Figure 1. An illustration of the EAC.

Chapter 2: Related Works

2.1 Introduction

The broadcast storm problem refers to excessive rebroadcasts and serious collisions caused by blind flooding. Flooding treats all nodes in the network equally; thus each node rebroadcasts each request exactly once. The method is blind since it does not address the environment situation. Many schemes have been developed to address this problem, and are categorized as probability-based and neighbor-knowledge schemes. Some typical schemes in both categories are briefly discussed below.

2.2 Previous Work

A. Probability based schemes.

In probability based schemes, each node in the network makes a rebroadcast decision on its own. A pure probabilistic scheme [1] assigns uniform probability to every node in the network. Clearly, these methods are not appropriate for various network topologies in MANETs. A distance-based scheme [3, 6] depends on the distance between a node and its detectable broadcast source. If the distance is longer than the predefined threshold, then it rebroadcasts; otherwise, the request is dropped. A counter-based scheme adopts the congestion condition of a node's neighborhood. Rebroadcast is only performed if the number of its detectable neighbors is smaller than the predefined threshold.

B. Neighbor-knowledge schemes [2] [10]

The main advantage of neighbor-knowledge based schemes is that they make precise rebroadcast decisions. Topology information is critical to making such precise decisions. However, the additional overhead which arises from gathering topology information is the most arguable. The mobility would even deteriorate the performance since more control packets are required to keep the topology information correct. One-hop and two-hop neighbor information are most frequently used. Since the hello packets are relatively small, most schemes neglect the overhead arising from gathering topology information.

2.3 DISCOUNT Algorithm

The goal of DISCOUNT scheme is that the border nodes are endowed with higher probability to rebroadcast while the rebroadcast probability of interior nodes depends on how congested the network is. We introduce two metrics, interior counter threshold (ICth) and distance threshold (Dth), to achieve the goal. As shown in Figure 2, node S is a source node. R denotes the transmission range (we suppose all nodes in the network have the same transmission range). The nodes lay within R but not in Dth are referred as border nodes (e.g. node A and B) and the nodes lay within Dth are referred as interior node (e.g. node C and D). Dth separates border nodes from interior nodes and ICth indicates how congested the network is.

First of all, the source node starts a broadcast request. All of its neighbors will start a RAD (Random Assessment Delay) to listen for duplicated messages upon receiving the broadcast message from the source. At the same time, interior nodes increase their counter to 1. Interior nodes work similar to the counter-based scheme. It increases the counter by one while hearing a duplicated interior message during RAD. If the counter goes beyond ICth, the rebroadcast will be blocked. Otherwise, the rebroadcast will be sent out when RAD expires. The border nodes work like distance-based scheme which rebroadcasts the message if no other interior redundant messages have been received before RAD expires. Take Figure 2 for example. Suppose every node sets its counter to 0 (counter of D is represented as CD) at the beginning. As source node S starts a broadcast, all of its neighbors start their RAD and the interior nodes will increase their counter by one (e.g. CD=CE=1 now) and the counters of border nodes won't be increased (e.g. CA=CB= CC=0). If the RAD of node A expires first, node A rebroadcasts the message. As if receiving a duplicated broadcast message, the interior nodes of node A increase their counter by one (e.g. CB=1 and CD=CE=2) and the border node of node A keeps its original value (e.g. CC=0). The process goes on until every RAD expires. Let us look deeper into the example. We can observe that the node located closer to other hosts owns greater counter value. This implies that it has higher probability to go beyond the ICth and rebroadcast will be suppressed easily.

DISCOUNT algorithm is a hybrid scheme. It takes the advantages from both Counter-Based and Distance-Based schemes. Thus, in dense networks, a large Dth ensures a high rebroadcast probability of border nodes which improves EAC significantly. At the same time, rebroadcasts of interior nodes will be suppressed by the ICth to reduce unnecessary retransmission. In sparse networks, a small amount of non-rebroadcast nodes may lead to network partition and cause great harm to the reachability. To avoid such situation, with the help of ICth DISCOUNT, encourage interior nodes to rebroadcast unless they are in the excessively congested area. Apparently, DISCOUNT algorithm will degrade to become a Distance-Based scheme by setting ICth=1 and a Counter-Based scheme by setting Dth=250.

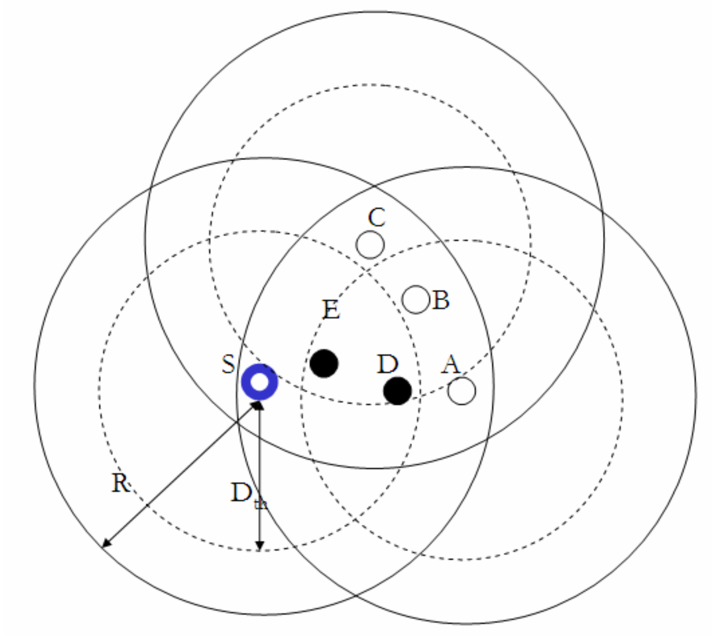

Figure 2: A DISCOUNT broadcast example

2.4 DIS_RAD Algorithm

An efficient broadcast scheme was developed in this study. A scheme named “DIS_RAD” which introduces the distinct range of RAD into the counter-based broadcast scheme in MANETs, was proposed. The nodes with higher EAC are given a shorter RAD, meaning that they expire earlier to first determine whether to rebroadcast the packets. Conversely, nodes with lower EAC are given a longer RAD, which makes these nodes more likely to be blocked because the rebroadcast packets of short RAD nodes may increase the counters of long RAD nodes.

Tseng et al [2] indicated that border nodes have higher EAC than interior nodes. Therefore, we introduce a distance threshold (D_{th}) which is less than or equal to communication radius (R) in the counter-based scheme, to separate the border nodes from the interior nodes. As shown in Fig. 3, node A denotes the source node, and R denotes the transmission range (all nodes in the network are assumed to have the same transmission range). The nodes lying within node S's transmission range but outside the range of D_{th} are called border nodes (e.g. node B and C). The nodes lying within D_{th} are called interior nodes (e.g. node D and E).

The proposed algorithm runs as follows. First, the source node initiates a broadcast request. All of its neighbor nodes increase their counters as soon as they receiving the broadcast message. The border nodes initiate an SRAD, and interior nodes initiate an LRAD, where the LRAD is always longer than the SRAD. The remaining procedure is the same as counter-based scheme. Nodes increase their counters by 1 when hearing a duplicated message during RAD. When the RAD expires, if the nodes' counters exceed the counter threshold (C_{th}), then the rebroadcast is blocked. Otherwise, the broadcast packets are sent out.

The following serves as an example. In Fig. 3, suppose that C_{th} is set to 3, and that each node initializes its counter value to 0. The notation C_B represents the counter of node B. When source node A initiates a broadcast request, all of its neighbors increase their counter to 1 (i.e. $C_B = C_{BC} = C_D = C_E = 1$). Nodes B and C have SRADs since they are located at the border, and their RADs expire before the RADs of nodes D and E, which are LRADs. Since counters C_B and C_C are less than 3, node B and C rebroadcasts the message. Counters C_D and C_E are increased to 3; thus nodes D and E are suspended from rebroadcasting when their RADs expire. If the RAD timer of nodes D and E expire first, which is possible in the counter-based scheme, then nodes B and C are blocked. As shown in Fig. 3, the EAC of nodes D and E are much smaller than the EAC of nodes B and C.

The value of D_{th} also affects the performance of DIS_RAD. Taking extreme cases the highest and lowest values of D_{th} (D_{th} = R and D_{th} = 0) degenerate the DIS_RAD scheme to a counter-base scheme. A large D_{th} should perform better than a small D_{th}, since border nodes always have large EAC values. Special cases often emerge from the networks with sparse node densities. Thus, the correct D_{th} value must be found for all network densities. Section Ⅴpresents the effect of D_{th} on overall performance through simulation results.

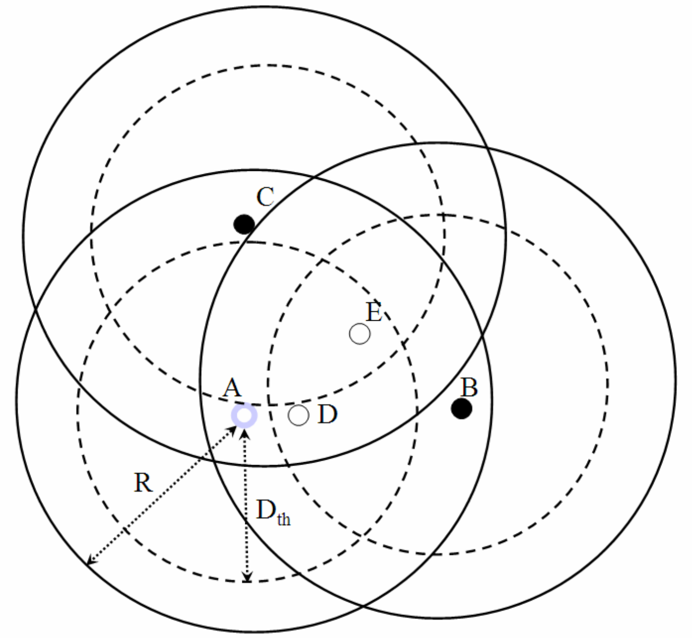

Figure 3. An example of DIS_RAD

2.5 DISCOUNT-RS

We must now return to the example in section 2.3. Suppose that ICth is set to 2 at the beginning which means that the rebroadcast of a node will be suppressed when its counter grows equal to or greater than 2. Let us resume the process of the example. Currently, node S and A have done their transmission and CC=0, CB=1 and CD=CE=2. Under the circumstance, the rebroadcast of node D and E are blocked by DISCOUNT scheme. The counters of node B and C, however, both are not yet exceeded. It is obviously that the coverage area of node B overlaps seriously with nodes A and C. In other words, it is unnecessary for node B to rebroadcast the message. Unfortunately, the probability that RAD of node B expires first and starts the rebroadcast is 1/2. This is because node B and C choose their RAD randomly at the same time when they receive the request from source node. In order to avoid the situation, the DISCOUNT scheme should be improved if rebroadcast number is concerned as a more important issue than reachability.

The main purpose of DISCOUNT-RS is to reduce the unnecessary rebroadcast of border nodes. We don’t try to reduce the rebroadcast probability of interior nodes because they already hold an extremely low rebroadcast probability. We introduce a condition to help a border node decide whether to rebroadcast or not in order to save more rebroadcast. The condition is described as follows. Similar to DISCOUNT scheme, each node determines whether it is a border or interior node as soon as it receives a new broadcast request. On one hand, if it is an interior node, it simply applies to the original DISCOUNT scheme. On the other hand, when it is a border node, it decides whether to rebroadcast or not according to received duplicated rebroadcast requests before its RAD timer expires. If the duplicated rebroadcast request comes from the interior area of the listening node, the rebroadcast of the node will simply be suppressed; otherwise, if the duplicated rebroadcast request comes from interior area, the node just keeps operating as DISCOUNT scheme.

We must now return to the example postponed in the last paragraph. At that time, we cannot choose rebroadcast between node B and node C cleverly. For the moment, rebroadcast of node B will simply be suppressed and node C will set out the rebroadcast after RAD timer expires. This is because node B is destined as a border node related to source node and then node B receives a duplicated packet from node A which is an interior node of node B.

DISCOUNT-RS is an enhancement algorithm of DISCOUNT scheme. It takes the advantages from reducing unnecessary rebroadcast of border nodes. The main purpose of the algorithm is to save more rebroadcast. On the contrary, the algorithm may cause some degradation to the performance of reachability. We will show the influences of DISCOUNT-RS on overall performance through simulation results in next section.

2.6 Analytical Model

This section presents a formal analysis of broadcast probability for the DIS_RAD algorithm. In [7], Tracy et al. proposed a predictive probability model of the counter-based scheme. Since the proposed scheme adds the concept of distance concept to the counter-based scheme, the analysis becomes more complicated. Two rebroadcast probabilities for the border and interior nodes need to be deduced. Because the RAD of the border nodes is shorter than that of the interior nodes, the rebroadcast probability of border nodes should be higher than that of interior nodes

As in [7], several assumptions were made to simplify the analysis process. First, the size of an area can represent the number of nodes located in that area. Second, each node in the network is independent, and moves unaffected by any other nodes. That is, the topology is regarded as uniformly distributed at any time. Third, the broadcast requests are generated randomly from all nodes in the network. The DIS_RAD analysis is likely to be workable in a network with these properties.

As mentioned earlier the broadcast probability is divided into two components, broadcast probability of interior nodes (P_i) and of border nodes (P_b). The probability of an individual node cannot be precisely predicted. However, this analysis gives a general trend of the rebroadcast probability under DIS_RAD.

In a DIS_RAD scheme, each node initiates a RAD as soon as it receives a new broadcast packet. The length of a node's RAD is determined by its relative distance from the source node. When the RAD expires, each node rebroadcasts the packet only if its counter is less than the counter threshold. The counter of each node is increased by 1 for each duplicated rebroadcast packet received before its RAD expires. Therefore, the probability that a node increases its counter must be deduced. The analysis starts as follows [7].

When node *v* receives a duplicated packet from node *u*, three conditions must apply:

A. Node *u* must be a neighbor of node *v*.

B. Node *u* must transmit the packet.

C. Node *u* must have a shorter RAD than *v*.

Since the broadcast signal propagation delay can be neglected, nodes *u* and *v* are assumed to have received the original broadcast request from the source node simultaneously.

Supposing that these three events are independent, the probability Q that node *v*'s counter increases by 1 can be obtained as follows:

$$Q = P(A \cap B \cap C) = P(A) \cdot P(B) \cdot P(C)$$

The parameters P(A), P(B) and P(C) separately as the followings. Parameter P(A) denotes the probability that node u locates within node *v*'s transmission range, and is calculated as:

$$P(A) = \frac{\pi R^2}{A_{net}} \tag{1}$$

Where R denotes the transmission radius and A_{net} denotes the entire network cover area. In DIS_RAD, the distance concept divides the rebroadcast probability into P_i and P_b. When node v receives a packet from an imaginary source, its position is determined according to two cases.

Case I: Given a distance threshold D_{th}, node v is located at the border annulus if its distance from the source is greater than D_{th}. Therefore the broadcast probability of *v* is given by P_b. When node *v* receives a duplicate packet from node *u*, in counter-based rebroadcast model proposed by Tracy et al., the location of node *u* is insignificant as long as it falls into node *v*'s transmission radius. In the proposed algorithm, however, the position of node *u* affects the probability of increment of the *v* counter. Therefore, two situations are considered:

S1: Node *u* is located at interior circle of source node, as shown in Fig. 4(a). The probability S1 is given as:

$$P(S1) = \frac{\pi D^2}{\pi R^2} = \frac{D^2}{R^2}$$

Since the border nodes are assumed to have the same rebroadcast probability equal to P_b, and the interior nodes have the same rebroadcast probability equal to P_i, the rebroadcast probability of node *u* is given by:

$$P(B_{S1}) = P_i \qquad (2)$$

Under S1, node *v* is destined an SRAD since it is located at the border annulus, while node *u* is destined an LRAD since it is located at the interior circle. Since node *v*'s RAD expires earlier than that of node *u*, node *v* does not receive a duplicated packet from node u before its RAD expires. Therefore, P(C) under S1 (referred as P(CS1)) equals zero.

$$P(C_{S1}) = 0 \cdot P(S1) = 0 \cdot \frac{D^2}{R^2} = 0 \qquad (3)$$

S2: Node *u* is located at border annulus of the source node, as shown in Fig. 4(b). The probability S2 is given as:

$$P(S2) = (\frac{\pi R^2 - \pi D^2}{\pi R^2}) = (1 - \frac{D^2}{R^2})$$

Since node *u* is now located at the border annulus, the rebroadcast probability of node *u* is known as:

$$P(B_{S2}) = P_b \qquad (4)$$

Under S2, node *v* and node *u* are both located at the border annulus, so both are destined SRADs. Since the two nodes have the same range of RAD (SRAD), the probability that node *u*'s RAD expires first is 1/2, because RADs are chosen randomly, and nodes *v* and *u* are assumed to receive the same broadcast request simultaneously (the signal propagation delay is negligible). Thus, P(CS2) is given as:

$$P(C_{S2}) = \frac{1}{2} \cdot P(S2) = \frac{1}{2} \cdot (1 - \frac{D^2}{R^2}) = \frac{1}{2} - \frac{D^2}{2R^2} \qquad (5)$$

With (1)、(2) 、(3)、(4) and (5), the probability Q_b, that node *v*'s counter increases by 1 when node *v* is located at the border annulus, is computed by summing S1 and S2:

$$Q_b = P(A) \cdot P(B) \cdot P(C)$$
$$= P(A) \cdot P(B_{S1}) \cdot P(C_{S1}) + P(A) \cdot P(B_{S2}) \cdot P(C_{S2})$$
$$= (\frac{1}{2} - \frac{D^2}{2R^2}) \frac{\pi R^2 P_b}{A_{net}}$$

Equation (6) describes the probability that the counter of node *v* is increased by 1 by any other node in the network. Therefore, P_b can be computed by summing all possible scenarios when 0 to $C_{th}-1$ duplicated packets are received before node *v*'s RAD expires. Since the imaginary source definitely increases the counter value of node *v* from 0 to 1, only 0 to $C_{th}-2$ cases need to be considered. This is leading to:

$$P_b = \sum_{i=0}^{C_{th}-2} C_i^{N-2} Q_b^i (1 - Q_b)^{N-2-i} \qquad (7)$$
$$= \sum_{i=0}^{C_{th}-2} C_i^{N-2} ((\frac{1}{2} - \frac{D^2}{2R^2}) \frac{\pi R^2 P_b}{A_{net}})^i (1 - (\frac{1}{2} - \frac{D^2}{2R^2}) \frac{\pi R^2 P_b}{A_{net}})^{N-2-i}$$

The value of P_b is obtained by solving Eq. (7).

Case II: Given a distance threshold D_{th}, node *v* is located at the interior circle if its distance from the source is less than D_{th}. Likewise, two situations are discussed according to the position of node *u*:

S3: Node *u* is located at the interior circle of the source node, as shown in Fig. 5(a). The probability of S3 is given as:

$$P(S3) = \frac{\pi D^2}{\pi R^2} = \frac{D^2}{R^2}$$

The rebroadcast probability of node *u* is given by:

$$P(B_{S3}) = P_i \tag{8}$$

Under S3, both nodes *v* and *u* are located at the interior circle, and share the same RAD range (LRAD). As with S2, the probability that node u's RAD expires first is given by 1/2. Thus, P(CS3) is represented as:

$$P(C_{S3}) = \frac{1}{2} \cdot P(S3) = \frac{1}{2} \cdot \frac{D^2}{R^2} = \frac{D^2}{2R^2} \tag{9}$$

S4: Node *u* is located at the border annulus of the source node, as shown in Fig. 5(b). The probability of S4 is given by:

$$P(S4) = (\frac{\pi R^2 - \pi D^2}{\pi R^2}) = (1 - \frac{D^2}{R^2})$$

The rebroadcast probability of node *u* is given by:

$$P(B_{S4}) = P_b \tag{10}$$

Under S4, node *u* is located at the border annulus and is attached with SRAD, while node *v* is attached with LRAD according to the DIS_RAD scheme. Therefore the node *u*'s RAD expires prior than node v. Thus the probability that node *u* causes node *v*'s counter to be increased is 1.

$$P(C_{S4}) = 1 \cdot P(S4) = 1 \cdot (1 - \frac{D^2}{R^2}) = (1 - \frac{D^2}{R^2}) \tag{11}$$

The value of Qi　is derived from (1)、(8)　、(9)、(10) and (11); Hence, the probability that node *v*'s counter increases by 1 when node *v* is located at the interior circle is given by:

$$\begin{aligned} Q_i &= P(A) \cdot P(B) \cdot P(C) \\ &= P(A) \cdot P(B_{S3}) \cdot P(C_{S3}) + P(A) \cdot P(B_{S4}) \cdot P(C_{S4}) \\ &= \frac{D^2}{2R^2} \cdot \frac{\pi R^2 P_i}{A_{net}} + (1 - \frac{D^2}{R^2}) \cdot \frac{\pi R^2 P_b}{A_{net}} \end{aligned} \tag{12}$$

From (12), P_i can be calculated by summing all possible Qi values as the same method when calculating P_b. Therefore,

$$
\begin{aligned}
P_i &= \sum_{i=0}^{C_{th}-2} C_i^{N-2} Q_i^i (1-Q_i)^{N-2-i} \\
&= \sum_{i=0}^{C_{th}-2} C_i^{N-2} \left(\frac{D^2}{2R^2}\cdot\frac{\pi R^2 P_i}{A_{net}} + (1-\frac{D^2}{R^2})\cdot\frac{\pi R^2 P_b}{A_{net}}\right)^i \cdot \\
&\left(1-\left(\frac{D^2}{2R^2}\cdot\frac{\pi R^2 P_i}{A_{net}} + (1-\frac{D^2}{R^2})\cdot\frac{\pi R^2 P_b}{A_{net}}\right)\right)^{N-2-i}
\end{aligned} \qquad (13)
$$

The value of P_i can be derived with Eq. (13).

From the analysis above, P_b and P_i can be compared with the broadcast probability in the counter-based scheme analyzed in [3], given by P_c by observing the curve of the analytical results. Figures 6, 7, 8 and 9 show various L×L maps analyzed using MATLAB, where L denotes a multiplier of the length of the communication radius R, which was set to 250 meters. Hence, the area of a network A_{net} equals 250×250×L×L m^2. The number of nodes N was set to 100, and counter threshold C_{th} was set to 3. The X-axis denotes the value of D_{th}, and the Y-axis denotes the probabilities calculated by the analytical models. Clearly, P_b approximates P_c when D_{th} approaches 0, while Pi approximates P_c when D_{th} is set to 250 (equals R). In both cases, DIS_RAD is degenerated into the counter-based scheme.

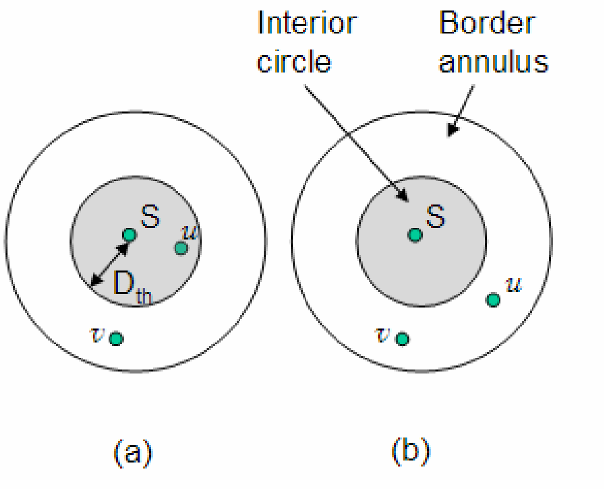

Figure 4. The cases where node *v* locates at the border annulus.

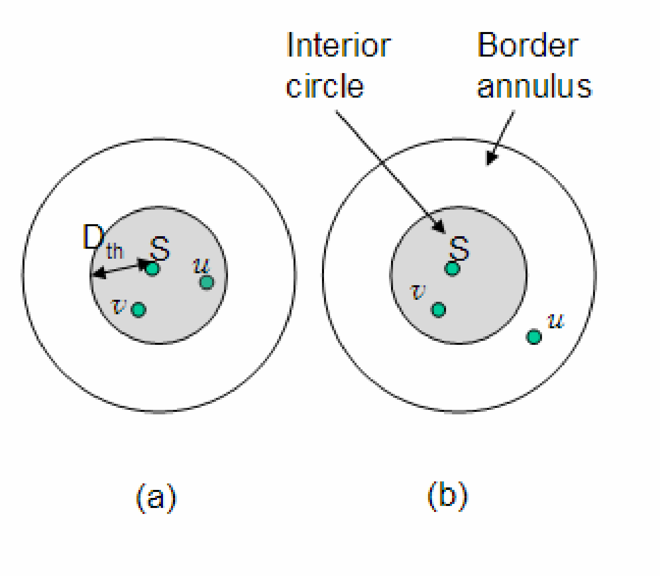

Figure 5. The cases where node *v* locates at the interior circle.

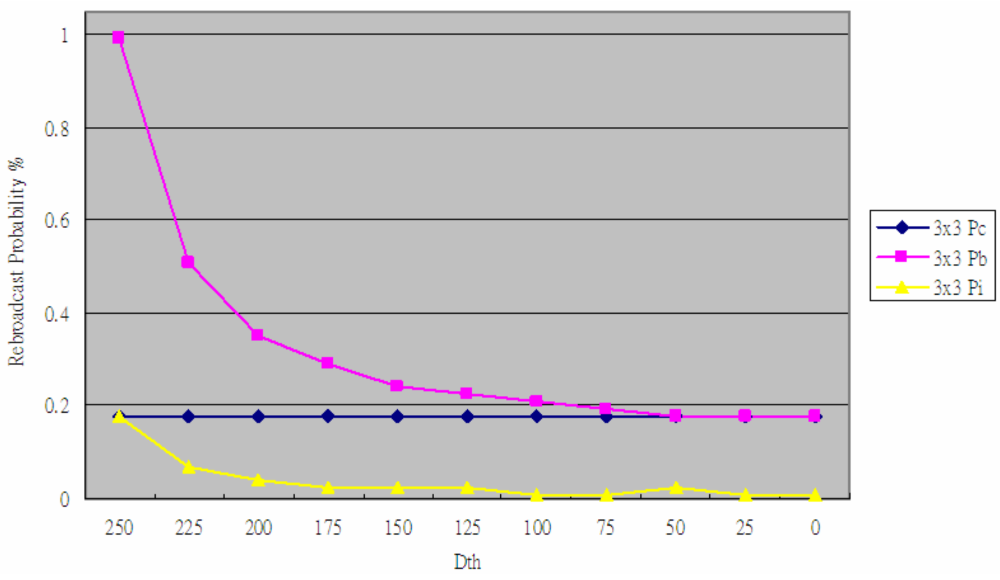

Figure 6. P_b, P_i and P_c vs. D_{th} with C_{th}=3 in 3×3 map

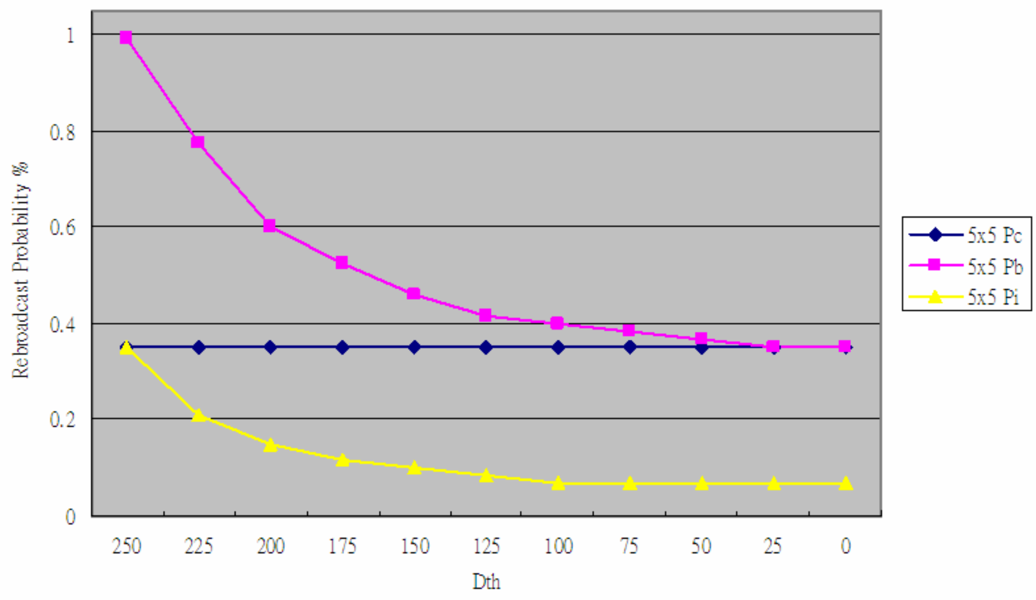

Figure 7. P_b, P_i and P_c vs. D_{th} with C_{th}=3 in 5×5 map

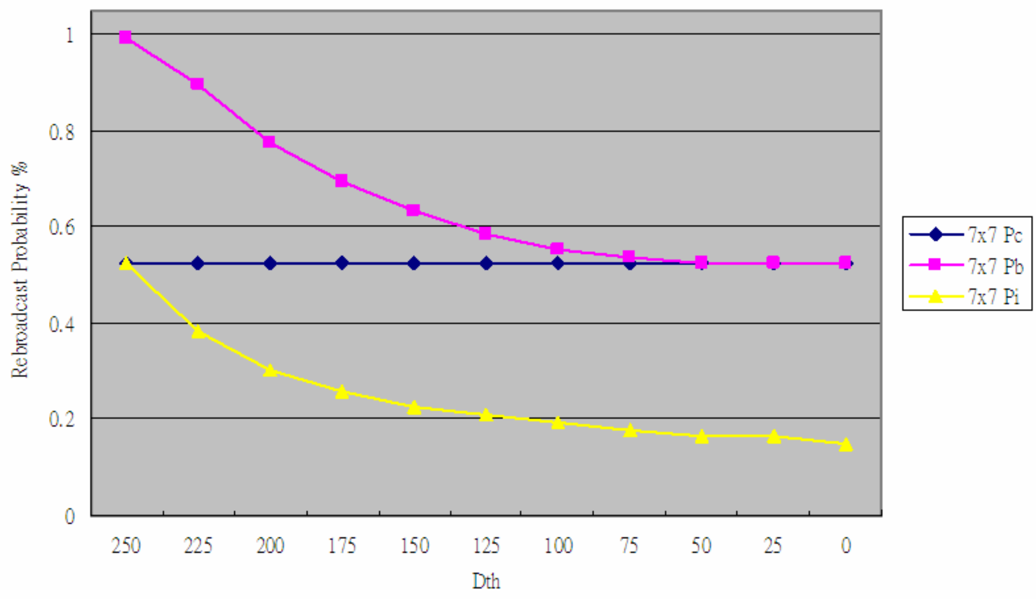

Figure 8. P_b, P_i and P_c vs. D_{th} with C_{th}=3 in 7×7 map

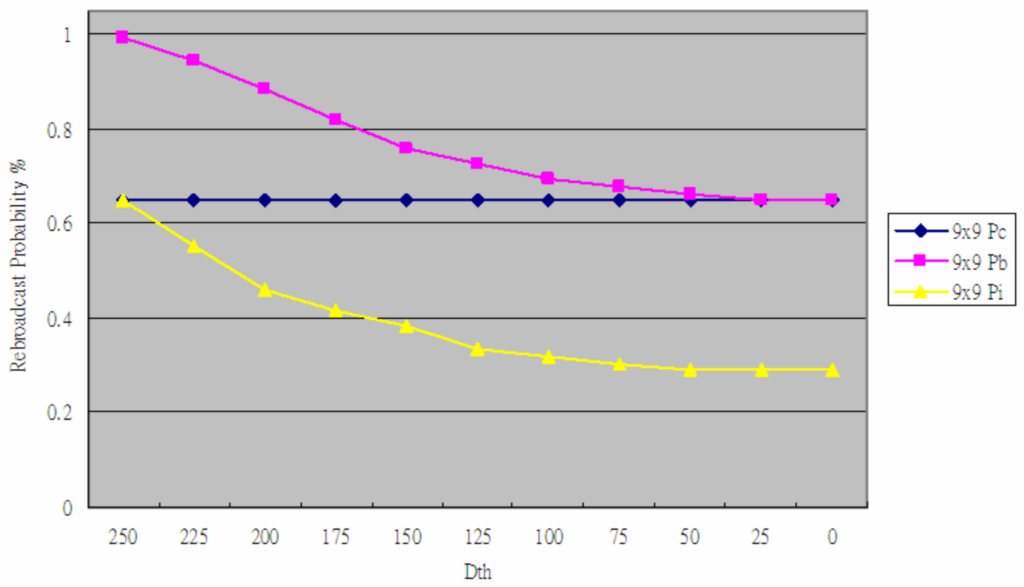

Figure 9. P_b, P_i and P_c vs. D_{th} with C_{th}=3 in 9×9 map

Chapter 3: Simulation Results

3.1 Simulation Environment

DIS_RAD was implemented using an NS-2 simulator. To ensure that the simulation results were comparable to others, the simulation environment was modeled on that in [1]. The simulation network contained 100 nodes placed randomly in a map of L×L units, where a unit is the length of communication radius set to 250 meters. The random waypoint model for mobility patterns was adopted. The topologies were generated randomly by the "setdest" program supported by NS-2. The moving speed was randomly distributed from 0 to 20 (m/s), and the pause time was set to 0. Each node in the network made a broadcast request exactly once during the 200 seconds of the simulation period. The MAC layer was constructed using the IEEE 802.11 standard, which is implemented in NS-2. The simulation results were averaged by the results of 15 simulation runs. The following two performance metrics were considered:

· RE – the percentage of nodes which can be REached as compared with blind flooding.

· SRB – the percentage of Saved ReBroadcasts as compared with blind flooding.

3.2 results of DISCOUNT and DISCOUNT-RS schemes

Figure 10 shows the performance of RE and SRB when the counter threshold ICth equals 2. We can observe that the performance of RE can only be satisfied (larger than 90%) in dense networks such as 3x3 and 5x5 maps. This is because a small number of rebroadcasts from border nodes are enough to cover the most part of the network area. When the network density becomes low, the nodes which are critical in maintaining a good RE are easily suppressed if the counter threshold is not big enough. Thus, we can observe that the RE performance is unacceptable under 7x7 and 9x9 maps. However, when the counter threshold ICth is increased to 3 and 4, as shown in Figure 11 and 12, it is obvious that the overall performance of RE is relatively satisfactory. Even when the networks are sparse, we also have about 90% of RE when ICth is 3. When the ICth increases to 4, the RE is almost perfect in most cases; however, we can observe the performance degradation of SRB is about 10% when the IC_{th} increases from 3 to 4. It is straightforward that the smaller the IC_{th} is, the better the SRB will be. However, it is important to keep both RE and SRB in acceptable values. To keep good balance between RE and SRB, we recommend that D_{th} should be set around 200 (80% of transmission radius) and the IC_{th} should be set to 3, where the optimal balance of RE and SRB performance can be observed. We can also observe that if D_{th} is set to a small value, RE decreases sharply. It is reasonable that if D_{th} is set too low (say smaller than 72 meters), the EAC of the border node may not be large enough to cause our algorithm to work almost the same as Counter-Based scheme. It's obvious that the DISCOUNT will be degenerated into a Counter-Based scheme when D_{th} is set to 250. From Figures 10, 11 and 12, we can find that DISCOUNT provides much better performance in RE in comparison with Counter-Based scheme. The detail comparison between Counter-Based scheme and DISCOUNT will be described later.

From the figures above, we can observe that when the networks are dense, it is easy to keep the RE high. When the networks are sparse, we cannot keep a good RE in all situations. Therefore, it is necessary to give a more detailed analysis under a sparse network. As shown in Figure 13, we compare the Counter-Based scheme with DISCOUNT scheme under 7x7 and 9x9 maps. The D_{th} is set to 225. SRB7x7C denotes the SRB under 7x7 map of Counter-Based scheme, and SRB7x7DC denotes the SRB under 7x7 map of DISCOUNT scheme. In an attempt to get the RE higher than 90%, Counter-Based scheme should adjust C_{th} to 4 or 5 for 7x7 map and 5 or 6

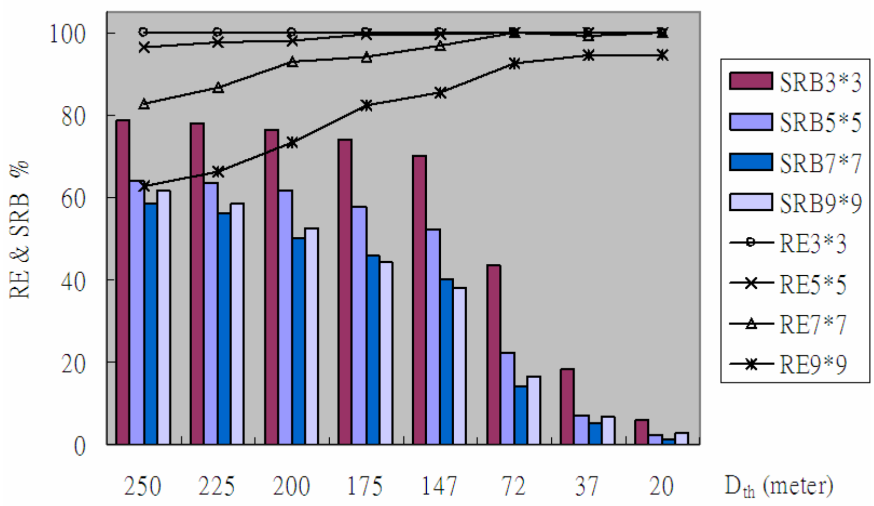

Figure 10.The performance of DISCOUNT scheme with $C_{th} = 2$

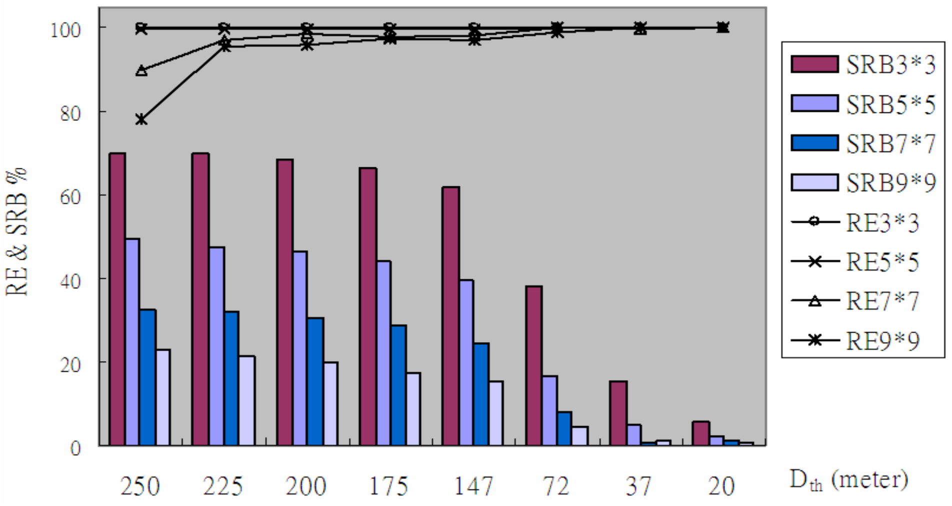

Figure 11.The performance of DISCOUNT scheme with $C_{th} = 3$

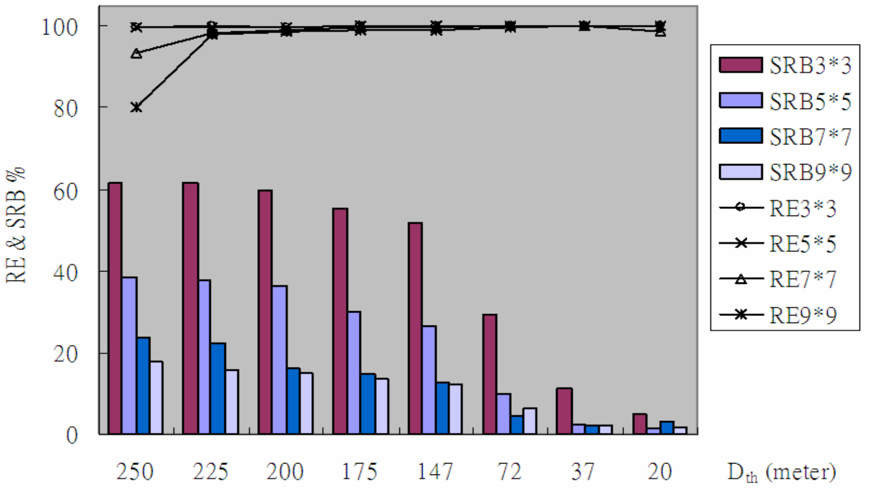

Figure 12.The performance of DISCOUNT scheme with $C_{th} = 4$

for 9x9 map respectively. However, when C_{th} increases to 5, the SRB of Counter-Based scheme is only about 11%. When C_{th} is 6, the SRB of Counter-Based scheme remains even less than 5%. On the contrary, DISCOUNT scheme can keep at least 90% of RE in both network topologies with C_{th} equals to 3. It also provides a much better SRB when compared with Counter-Based scheme. The SRB is 30% and 21% when C_{th} is 3 under 7x7 and 9x9 maps respectively. It is very clear that DISCOUNT outperforms Counter-Based scheme. We can also observe that DISCOUNT is not sensitive to the value of C_{th}. In Counter-Based scheme, one way to keep a good balance between RE and SRB for different network densities is to adjust C_{th} dynamically [4]; however, it is not practical since the network topology is not predictable. DISCOUNT maintains stable performance of RE under fix C_{th}.

As shown in Figure 14, we compare the Distance-Based scheme with DISCOUNT scheme under 7x7 and 9x9 maps. The C_{th} of DISCOUNT scheme is set to 3. SRB7x7D denotes the SRB under 7x7 map of Distance-Based scheme, and SRB7x7DC denotes the SRB under 7x7 map of DISCOUNT scheme. In an attempt to get the RE higher than 90%, Distance-Based scheme should adjust D_{th} to less than 72 meters for 7x7 map. While under 9x9 map, the RE cannot reach the 90% in all conditions. However, when D_{th} is set to less than 72 meters, the SRB of Distance-Based scheme is only about 17%. On the contrary, DISCOUNT scheme can keep at least 90% of RE in both network topologies with D_{th} about 225 meters. It also provides about 30% SRB under 7x7 map. It is obvious that DISCOUNT outperforms Distance-Based scheme. Figure 15 declares the reason why DISCOUNT scheme performs better than Distance-Based Scheme. PD denotes the rebroadcasts that caused by pure Distance-Based scheme and PC denotes the rebroadcasts that transmitted by the effect of counter threshold. When D_{th} is set to 225 meters, only 18% of rebroadcasts are transmitted by distance concept, and the other 82% of rebroadcasts is provided by counter concept. As we discussed before, the distance concept provides good EAC, and counter concept ensure critical nodes have the chance to rebroadcast.

Figure 16 shows the performance of DISCOUNT-RS scheme with C_{th} = 3. It shows that when D_{th} is bigger than 147 in 3x3 map, the SRB of DISCOUNT-RS achieves 75% which is higher than original DISCOUNT scheme in the same condition about 7%. DISCOUNT-RS achieves 10% higher in 5x5 and 7x7 maps, and almost 20% in 9x9 map. By the way, DISCOUNT-RS keeps good RE (larger than 90%) in 3x3, 5x5, and 7x7 maps but degrades rapidly in 9x9 map. When D_{th} is smaller than 175, we have only about 85% of RE which is not able to satisfy our request (at least 90%) but if D_{th} is set smaller than 175, the SRB is too low. As we said in the last section, DISCOUNT-RS is proposed to save more rebroadcast but may cause some digression to RE. From the simulation results, we find that DISCOUNT-RS keeps good performance when topology is not extremely sparse. It keeps almost the same RE but gets a higher SRB in these situations. Therefore, we will give a more detailed analysis under these situations.

As shown in Figure 17, we compare the DISCOUNT-RS with the DISCOUNT scheme under 3x3, 5x5, and 7x7 maps of different C_{th} with D_{th}=225. It shows that DISCOUNT-RS keeps almost the same RE comparing with original DISCOUNT scheme. The difference of SRB between DISCOUNT-RS and DISCOUNT scheme, however, grows with the increasing of C_{th}. When C_{th} =2, the difference is only 2%. As C_{th} =4, the difference grows to 9% in all maps. The results make us believe that DISCOUNT-RS is able to replace DISCOUNT scheme when the network topology is not extremely sparse.

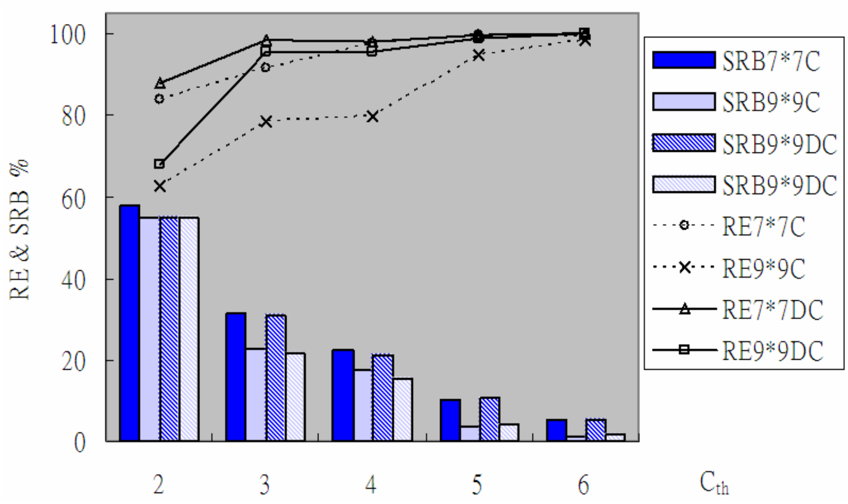

Figure 13. The performance comparison between counter-based and DISCOUNT scheme with D_{th} = 225

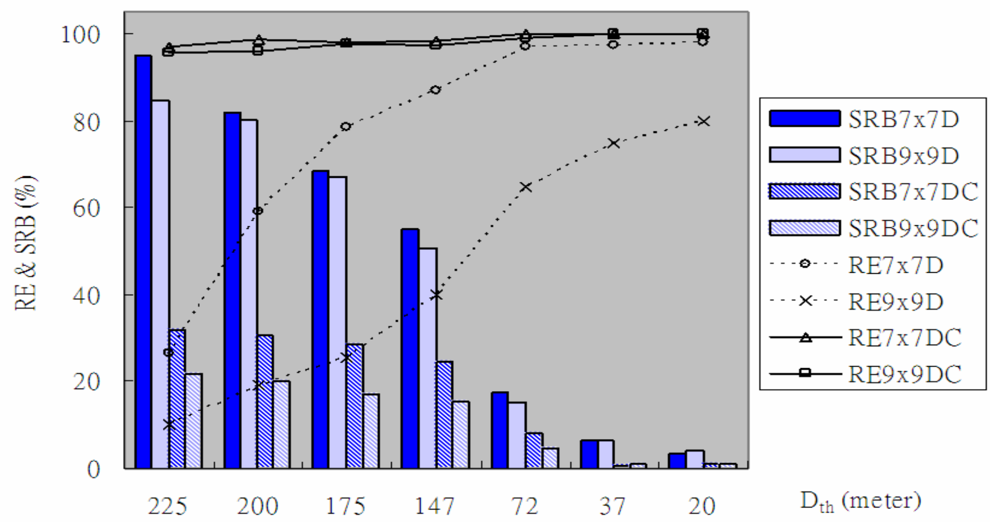

Figure 14. The performance comparison between distance-based and DISCOUNT scheme with C_{th} = 3

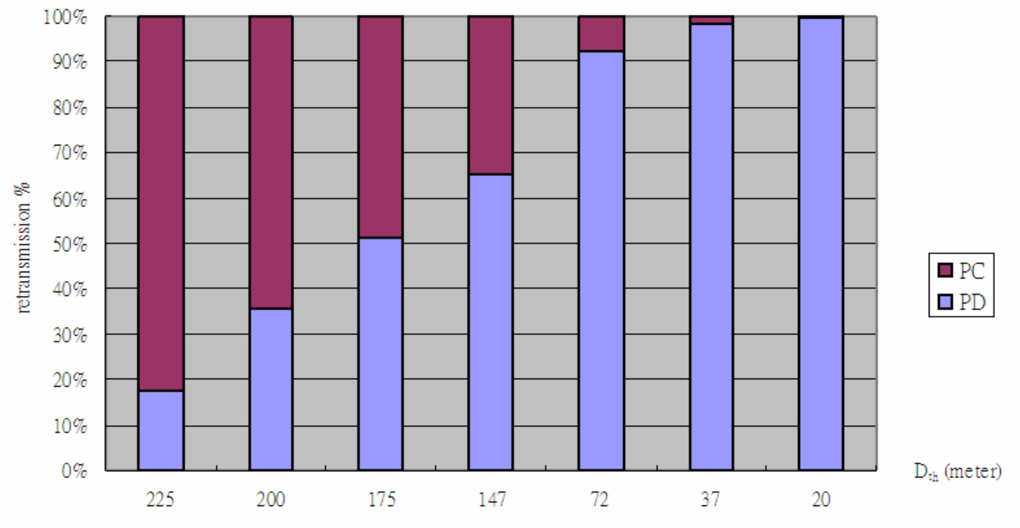

Figure 15. The proportion that rebroadcast protects by counter with C_{th} = 3 in 7x7map

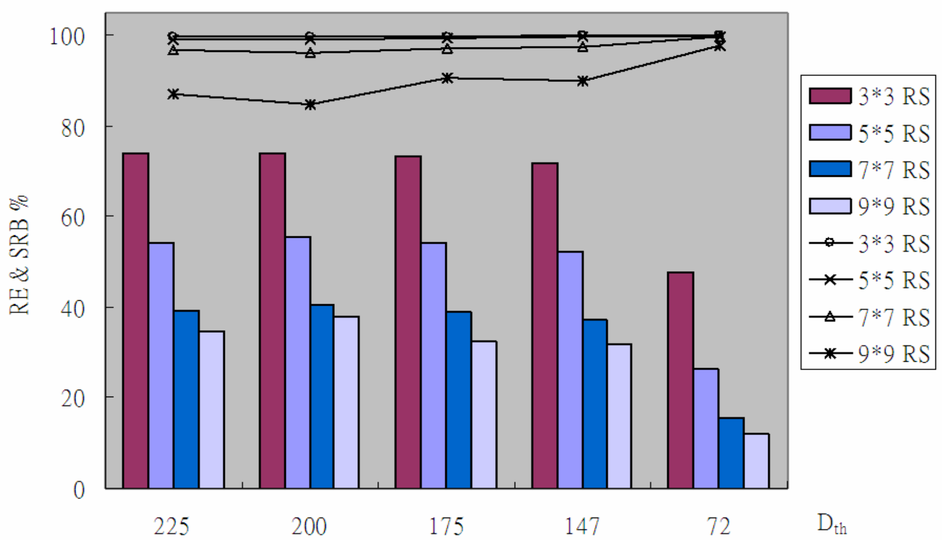

Figure 16. The performance of DISCOUNT-RS scheme with C_{th} = 3

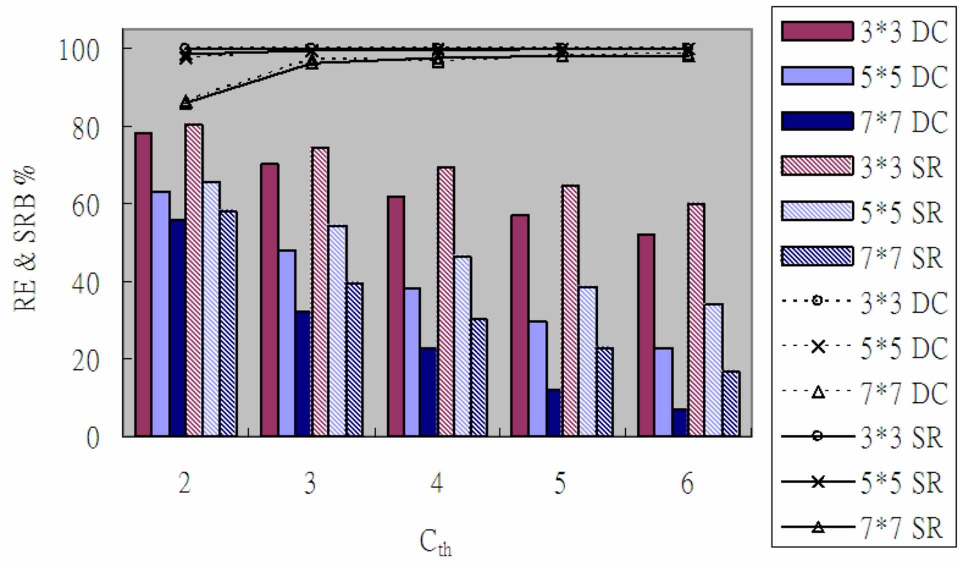

Figure 17. The performance comparison between DISCOUNT and DISCOUNT-RS scheme with D_{th} = 225

3.3 results of DIS_RAD scheme

Figure 18 shows the performance of RE and SRB when the counter threshold C_{th} = 2. The figure shows that the RE only performs well (larger than 95%) in dense networks such as 3×3 and 5×5 maps, since a small number of rebroadcasts from border nodes are sufficient to cover most of the network area. When the network density becomes low, the nodes, which are vital to maintaining a good RE, are easily suppressed if the counter threshold is not big enough. Hence, we can observe that the RE performance was found to be unacceptable under 7×7 and 9×9 maps.

However, when the counter threshold C_{th} was increased to 3 and 4, as shown in Figs. 19 and 20, the overall performance of RE was satisfactory. Even when the networks were sparse, RE was around 90% when C_{th} = 3. When C_{th} was increased to 4, the RE was almost perfect in most cases, but the performance degradation of SRB was about 10% when C_{th} increased from 3 to 4. Clearly a smaller C_{th} leads to a better SRB. However, both RE and SRB have to be kept in an acceptable range. To maintain a good balance between RE and SRB, D_{th} should be set around 200 (80% of the transmission radius), and C_{th} should be set to 3, where balance between RE and SRB was found to be optimal. Because, if D_{th} is set to a small value, RE decreases sharply. Hence, D_{th} is set too low (e.g., smaller than 100), then the EAC of the border node may not be sufficiently large for the proposed algorithm to work well. The extreme case is when $D_{th} = 0$. On the other hand, even a large D_{th} can yield a high EAC, and hence a high RE. However, when D_{th} is too large (e.g. greater than 200), the probability that a node is located in the border annulus is also small, especially in sparse networks. In other words, the number of nodes with good EAC values is too low to improve the performance. The RE decreases when D_{th} is set too high. The extreme case is when $D_{th} = 250$. Clearly, DIS_RAD is degenerated into a counter-based scheme when D_{th} is set to 0 and 250. Figures 18, 19 and 20 demonstrate that DIS_RAD always provides much better performance in RE than the counter-based scheme, and in some situations yields a better SRB. The counter-based scheme and DIS_RAD are compared in detail later.

The analysis above shows that RE remains high in dense networks. However, a good RE cannot always be maintained in a sparse network. Therefore, a detailed analysis is necessary for sparse networks. As shown in Figure 21, the counter-based scheme was compared with DIS_RAD for 7×7 and 9×9 maps, with D_{th} set to 200. The term SRB7×7C denotes the SRB using a 7×7 map in the counter-based scheme, and SRB7*7DR represents the SRB using a 7×7 map in DIS_RAD. To increase RE above 95%, a counter-based scheme should alter C_{th} to 4 or 5 for a 7×7 map, and 5 or 6 for a 9×9 map, respectively. However, when C_{th} increases to 5, the SRB of counter-based scheme is only about 11%. When $C_{th} = 6$, the SRB in the counter-based scheme remains below 5%. By contrast, DIS_RAD can keep RE above 95% of RE in both network topologies when C_{th} = 3, and yields a much better SRB than does the counter-based scheme. The SRB is 38% and 27% when C_{th} is 3 under 7×7 and 9×9 maps respectively. Clearly, DIS_RAD outperforms the counter-based scheme, and is not sensitive to the value of C_{th}. In the counter-based scheme, a good RE for different network densities can be maintained by adjusting C_{th} dynamically [4]; however, this approach is not practical since the network topology is not predictable. DIS_RAD maintains stable performance of RE under a fixed C_{th}.

To verify the analytical model of DIS_RAD rebroadcast probability, Figs. 6, 7, 8, and 9 were compared with rebroadcast probability obtained from the simulation results in Figs. 22, 23, 24 and 25. The X-axis represents the value of D_{th}, and the Y-axis represents the probability of rebroadcasting derived through simulations. The values of Pb are computed from the number of rebroadcasts made by the border nodes over all new distinct rebroadcast messages received by border nodes during the entire simulation period, and the values of P_i are computed in the same way. The parameter P_c represents the value of rebroadcast probability of the counter-based scheme. The probability trends from the simulation results were found to be similar to those from the analysis results. P_b approximates P_c when D_{th} approaches 0, and P_i approximates P_c when D_{th} is set to 250 (the value of R). In the simulation, the value of P_b does not exist when D_{th} is set to 250, because no border nodes exist. The same condition occurs with P_i when D_{th} = 0, because no interior nodes exist. Significantly, the analytical probability curves are lower than the simulation probability curves. This finding would be expected because the analysis did not consider the impact of the MAC layer. Therefore, packet collision, contention and delay could prevent some packets from reaching the network layer before a node's RAD expires. Consequently, the analytical rebroadcast probability may be too conservative. The same augment has been made in [7] for the counter-based scheme analytical rebroadcast probability (P_c).

As mentioned in section III, DIS_RAD separates the LRAD from the SRAD, where the LRAD is always longer than the SRAD. When the LRAD and SRAD are initiated, they fall into two different non-overlapping time slot ranges. The performance impacts on different ratio of the LRAD and SRAD ranges are discussed as follows. In previous simulations, equal numbers of time slots were set for both LRAD and SRAD ranges (ratio = 1). The RE and SBR performance were compared for three different ratios of LRAD to SRAD ranges, 0.5, 1 and 2. As shown in Fig. 26, the REs were almost the same for all ratios, but SRBs were slightly different, particularly for small D_{th}. At a ratio of 2, the SRB degraded by about 4−5% comparing a ratio of 1. Conversely, when the ratio was 0.5, the SBR improved by about 2–3% compared with a ratio of 1, because if the range of SRAD is too small, a node-assigned SRAD does not have enough time to collect sufficient neighbor information before making a rebroadcast decision, causing some unnecessary rebroadcasts to be sent. This performance impact can also be observed in Fig. 27, which plots the rebroadcast probabilities of border and interior nodes against the distance threshold D_{th}. The rebroadcast probability P_b when ratio = 2 is much higher than that when ratio = 1. This finding confirms the SBR performance degradation when the ratio is greater than 1. Similarly, the highest value of P_i occurs when the ratio is 0.5. However, as shown in Fig. 27, the difference between values of P_i under different ratios of LRAD and SRAD ranges is smaller than the difference between values of P_b. This finding is reasonable because most interior nodes are suppressed by border nodes when SRADs expire. Therefore, the performance influences from the interior nodes are minor compared with effects from the border nodes.

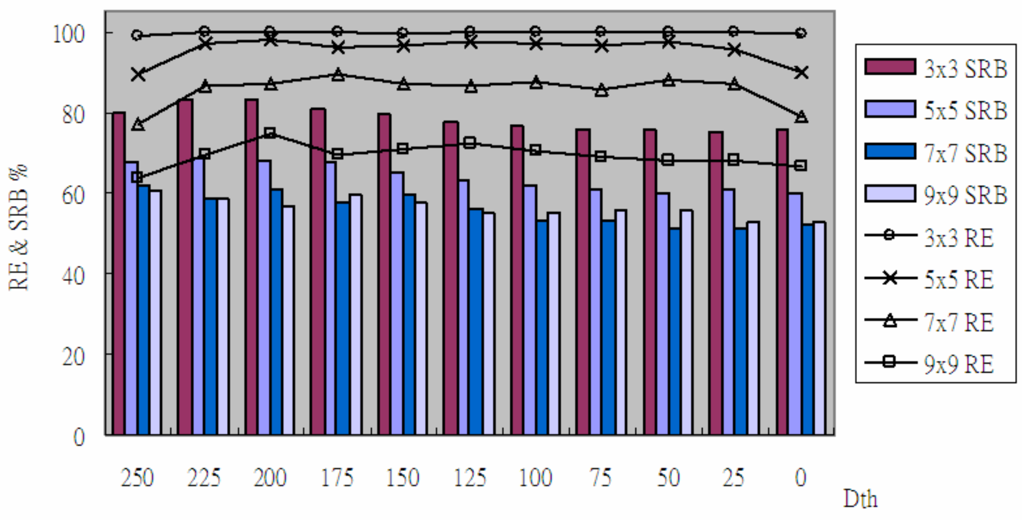

Figure 18. RE and SRB vs. D_{th} with $C_{th} = 2$

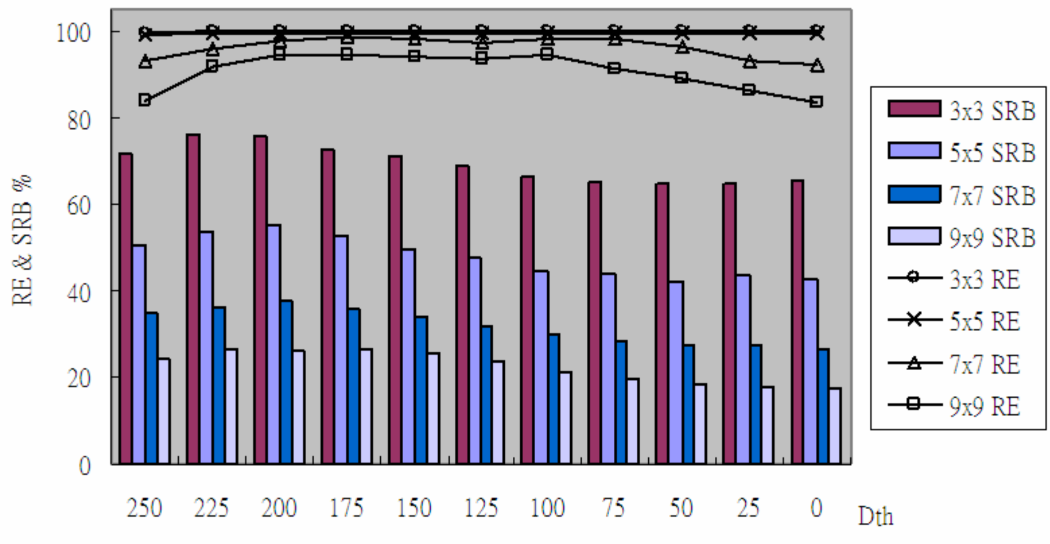

Figure 19. RE and SRB vs. D_{th} with $C_{th} = 3$

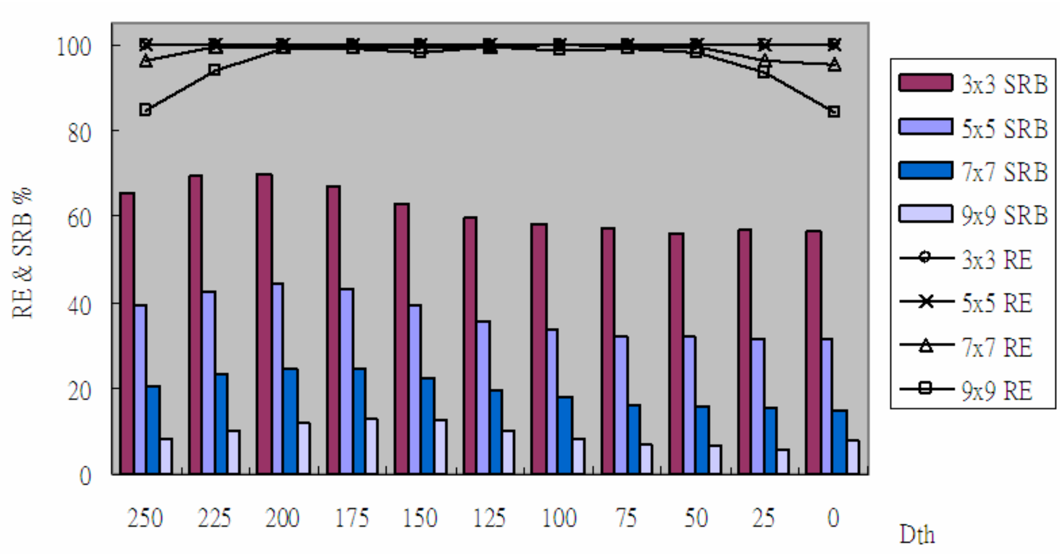

Figure 20. RE and SRB vs. D_{th} with $C_{th} = 4$

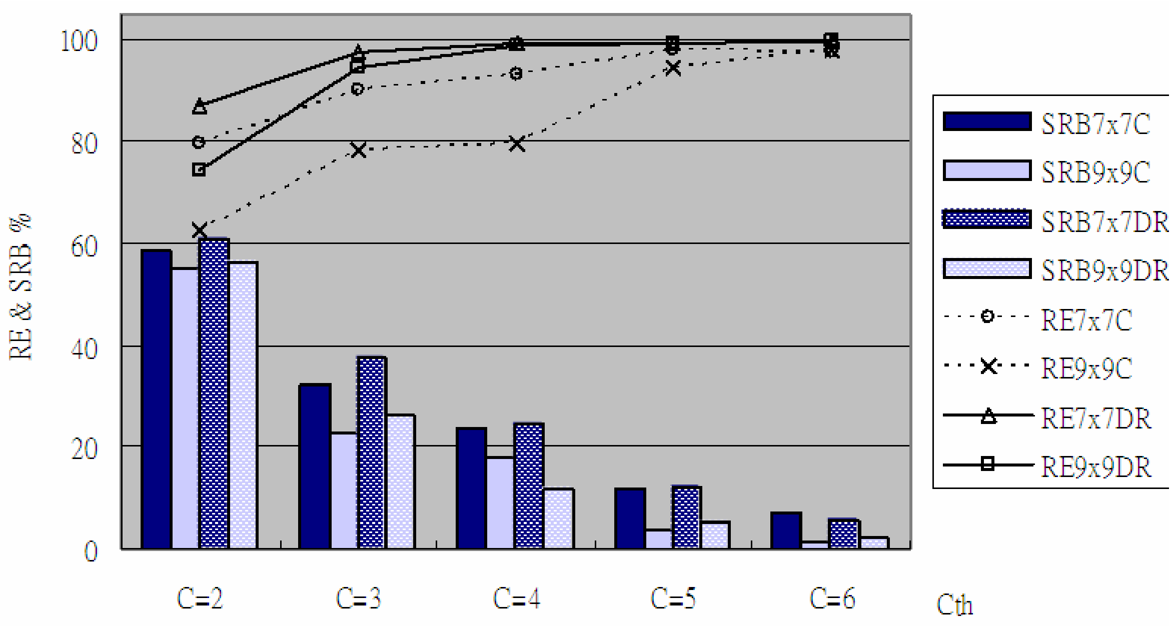

Figure 21. RE and SRB vs. C_{th} with $D_{th} = 200$

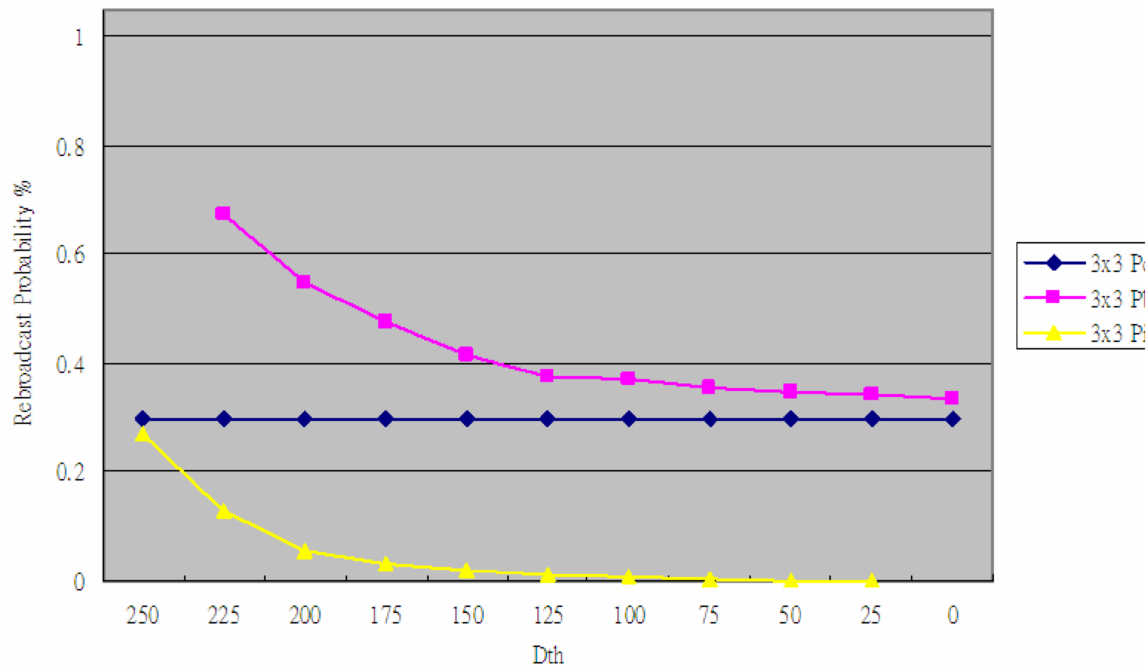

Figure 22. P_b, P_i and P_c obtained from simulation vs. D_{th} with C_{th}=3 in 3×3 map

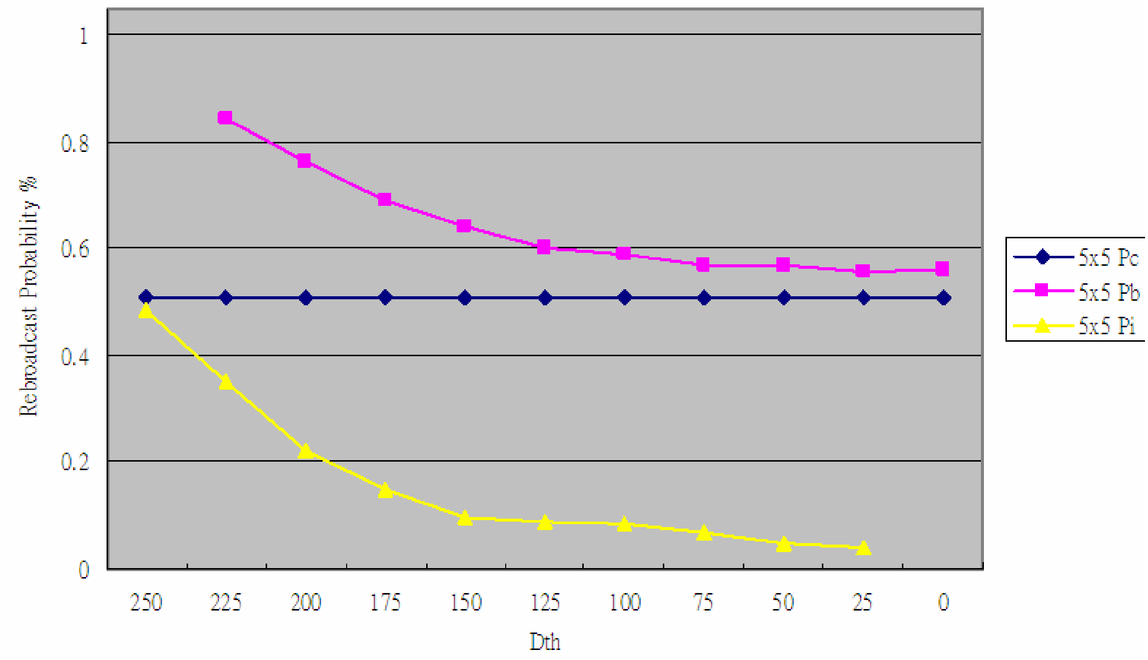

Figure 23. P_b, P_i, and P_c obtained from simulation vs. D_{th} with C_{th}=3 in 5×5 map

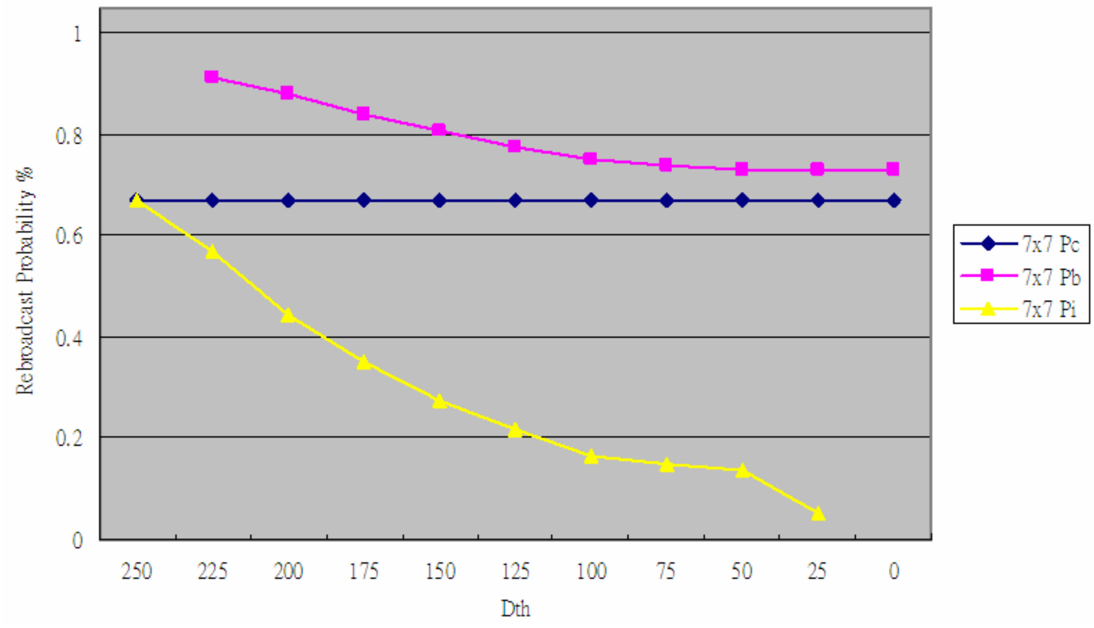

Figure 24. P_b, P_i and P_c obtained from simulation vs. D_{th} with C_{th}=3 in 7×7 map

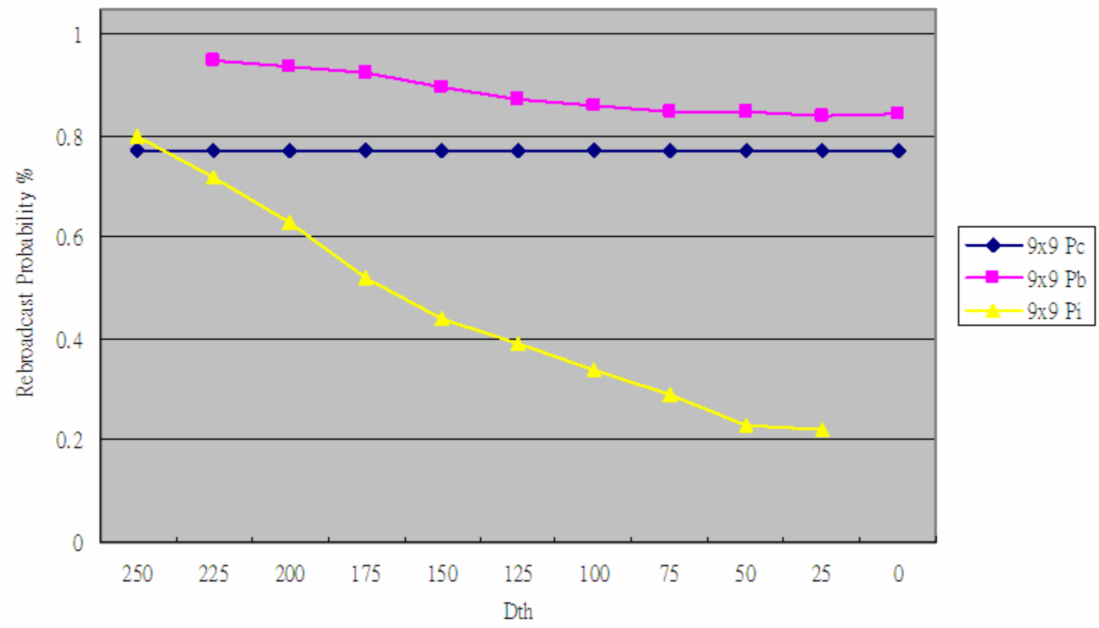

Figure 25. P_b, P_i and P_c obtained from simulation vs. D_{th} with C_{th}=3 in 9×9 map

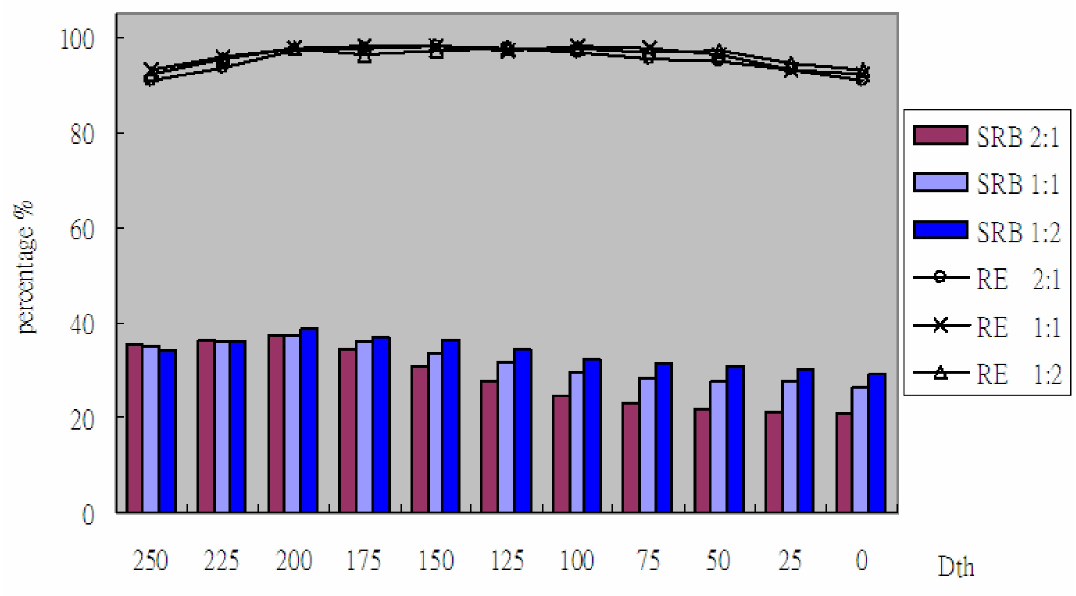

Figure 26. RE and SRB vs. D_{th} with different ratios of time slots in LRAD and SRAD ranges under C_{th}=3 in 7×7 map

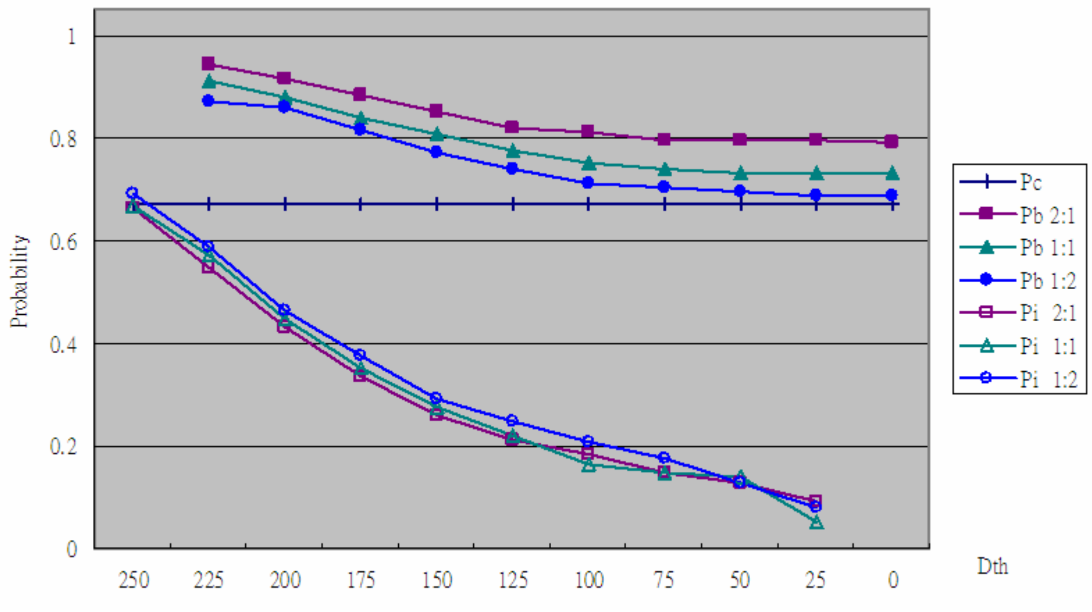

Figure 27. P_b, P_i and P_c obtained from simulation vs. D_{th} under different ratios of LRAD and SRAD ranges with C_{th}=3 in 7×7 map

Chapter 4: Conclusions and Future Works

This study proposed a distributed approach to resolve the broadcast storm problem. The counter-based scheme does not consider the locations of the nodes in the network. The proposed scheme addresses the distance concept by adding a D_{th} threshold to distinguish the interior circle from the border annulus. Border nodes, which have higher EAC, determine whether to rebroadcast prior to interior nodes. Nodes with higher EAC values are not suppressed by nodes with lower EAC values thus maintaining a high coverage. The number of rebroadcasts can also be minimized, since the interior nodes may be blocked by border nodes. The simulation results in Fig. 12 shows that when RE reaches 95%, DIS_RAD improved the SRB from 23% in the counter-based scheme to 37.5% for the 7×7 map, and from 3.9% in the counter-based scheme to 26% for the 9×9 map. Additionally, the proposed algorithm is easy to implement, and has some advantages applying to all network topologies can be observed. When D_{th} is set to about 200 meters, and the counter threshold is set to 3, the proposed scheme can keep good balance between reachability and rebroadcast efficiency in various network densities. However, the counter-based scheme assumes that the counter threshold can be adjusted dynamically to guarantee a good RE performance. Conversely, the proposed scheme is not sensitive to network topologies. This feature is likely to be essential for real world network implementations.

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