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Coverage-Aware Enhanced Self-Pruning for Efficient Broadcasting in Multi-Hop Wireless Networks

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Abstract

Reducing the number of forwarding nodes is a primary objective in broadcast protocols for multi-hop wireless ad hoc networks, as excessive redundant transmissions lead to the broadcast storm problem. Existing approaches can be broadly categorized into proactive and reactive techniques, where proactive methods such as Dominant Pruning (DP) utilize forwarding lists based on multi-hop neighborhood information, while reactive approaches like Self-Pruning (SP) allow nodes to decide locally whether to rebroadcast. Improved Self-Pruning (ISB) enhances this process by incorporating extended neighborhood knowledge; however, it relies on degree-based pruning, which does not accurately capture the effective coverage contribution of neighboring nodes. In this paper, we propose an Enhanced Self-Pruning (ESP) algorithm that employs a coverage-aware pruning strategy using extended 3-hop neighborhood information. Unlike ISB, ESP determines forwarding decisions based on the comparison of effective uncovered neighbor sets rather than raw node degrees, and further refines pruning by incorporating lightweight grandparent information through packet piggybacking. Extensive simulation results demonstrate that ESP significantly reduces the number of forwarding nodes compared to ISB and DP, and also outperforms

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the Extended Dominant Pruning (ExDP) algorithm, while maintaining low control overhead. These results indicate that coverage-aware pruning combined with extended neighborhood knowledge provides a more scalable and efficient solution for broadcast dissemination in wireless ad hoc networks.

Keywords: Broadcasting, Pruning Heuristics, Forwarding List, Overhead Analysis

1 Introduction

Broadcasting [1] is a fundamental communication primitive in multi-hop wireless ad hoc networks, where a source node disseminates a message to all other nodes in the network. It serves as a core component for numerous higher-layer protocols, including routing, resource discovery, and network management [2]. A straightforward flooding-based [3] broadcast approach, in which each node rebroadcasts a received packet exactly once, guarantees complete coverage but leads to excessive redundant transmissions, severe contention, and increased collision probability. This phenomenon is widely known as the broadcast storm problem [4] and significantly degrades network performance.

To mitigate this problem, a variety of broadcast reduction techniques have been proposed in the literature such as controlled flooding [5], probabilistic forwarding schemes [6], counter-based schemes [7], distance and/or location aided schemes [8–10], cluster-based schemes [11, 12] and neighbor knowledge schemes [13, 14]. These approaches can be broadly categorized into proactive and reactive methods [15]. In proactive approaches, such as Dominant Pruning (DP) [16], a forwarding node explicitly selects a subset of its neighbors as forwarders and includes this forwarding list in the packet header. While such methods can effectively reduce redundant transmissions by utilizing multi-hop neighborhood information, they incur additional communication overhead due to the appended forwarding lists, which may limit their scalability in dense networks. In contrast, reactive approaches, such as Self-Pruning (SP) [16], do not rely on explicit forwarding lists; instead, each node independently determines whether to rebroadcast a packet based on locally available neighborhood information, resulting in lower control overhead.

Improved Self-Pruning (ISB) [17] enhances the basic self-pruning mechanism by incorporating extended 3-hop neighborhood knowledge, enabling more informed forwarding decisions. Despite its effectiveness, ISB employs a degree-based pruning criterion, where nodes compare the number of neighbors to decide whether to forward a packet. However, node degree does not necessarily reflect the actual contribution of a node in covering previously uncovered neighbors. Consequently, this approach may lead to suboptimal pruning decisions, either retaining redundant forwarders or prematurely eliminating necessary ones. On the other hand, Extended Dominant Pruning (ExDP) [18] further reduces broadcast redundancy by also exploiting 3-hop neighborhood information, allowing more precise identification of coverage relationships. Nevertheless, such approaches typically rely on proactive forwarding strategies and incurs higher computational and communication control overhead.

In this paper, we address the limitations of existing pruning strategies by proposing an Enhanced Self-Pruning (ESP) algorithm that introduces a coverage-aware decision mechanism while maintaining the reactive nature of self-pruning. Specifically, similar to the ISB and ExDP algorithms, ESP also leverages extended 3-hop neighborhood information to improve coverage estimation and replaces the conventional degree-based comparison with a condition based on effective uncovered neighbor sets. Furthermore, ESP also incorporates lightweight grandparent information through packet piggybacking, enabling more accurate pruning without significantly increasing control overhead. By focusing on the actual contribution of nodes in covering uncovered regions, ESP achieves more precise forwarding decisions.
Extensive simulation results demonstrate that the proposed ESP algorithm significantly reduces the number of forwarding nodes compared to SP,ISB and DP across a wide range of network densities and transmission ranges. Moreover, ESP also consistently outperforms ExDP while relying on a reactive decision process and maintaining lower overhead. Additional analysis of control overhead further confirms that ESP achieves improved broadcast efficiency without incurring substantial communication cost and also consumes less energy than ExDP.
The main contributions of this paper can be summarized as follows:

We propose a coverage-aware Enhanced Self-Pruning (ESP) algorithm that improves broadcast efficiency by replacing degree-based pruning with effective coverage comparison. We incorporate extended 3-hop neighborhood information and lightweight grandparent piggybacking to refine pruning decisions. We perform a comprehensive performance evaluation against SP, DP, ISB, and ExDP under varying network conditions. We conduct detailed overhead analysis, demonstrating that ESP maintains low control overhead while achieving superior pruning performance.
The remainder of this paper is organized as follows. Section 2 reviews the related work. Section 3 presents the system model and preliminaries. Section 4 discusses the limitations of ISB. Section 5 introduces the proposed ESP algorithm. Section 6 presents an example scenario. Section 7 describes the experimental setup, followed by results and discussion in Section 8. Finally, Section 9 concludes the paper.

2 Related Works

Efficient broadcasting in wireless ad hoc networks has been extensively studied to address the broadcast storm problem caused by redundant transmissions. A large number of broadcast reduction techniques have been proposed in the literature, which can be broadly classified into flooding-based, proactive, and reactive approaches.
Flooding [3, 4, 19] is the simplest broadcasting mechanism in which each node rebroadcasts a received packet exactly once. Although flooding guarantees full coverage, it results in excessive redundant transmissions, increased contention, and packet collisions, especially in dense networks. To alleviate these issues, various optimized broadcasting techniques have been developed.
Proactive approaches reduce broadcast redundancy by explicitly selecting a subset of nodes as forwarders. One of the well-known techniques in this category is Dominant Pruning (DP) proposed by Lim and Kim [16], which utilizes 2-hop neighborhood

information to determine a minimal set of forwarding nodes that can cover all 2-hop neighbors of a transmitting node. While DP effectively reduces the number of transmissions compared to flooding, it requires maintaining and transmitting forwarding node lists in packet headers, thereby increasing communication overhead. Authors in [13], suggested two extensions of DP namely Partial Dominant Pruning (PDP) and Total Dominant Pruning (TDP). PDP deducts the neighbors of common neighbors of the sender and receiver nodes. TDP requires 2-hop neighbors of the immediate sender to be piggybacked within the broadcast packet. Rahman et al. [20], proposed Enhanced Partial Dominant Pruning (EPDP) which is an extension of PDP. Again to further improve pruning efficiency of the existing proactive pruning algorithms, Extended Dominant Pruning (ExDP) [18] has been proposed, which exploits 3-hop neighborhood information to more accurately identify redundant forwarders. By leveraging extended neighborhood knowledge, ExDP achieves better reduction in broadcast redundancy; however, the increased complexity and overhead associated with maintaining multi-hop information may limit its scalability in large networks.

In contrast, reactive approaches avoid explicit forwarding lists and allow each node to independently decide whether to rebroadcast a packet based on local neighborhood information. Self-Pruning (SP) also proposed by Lim and Kim [16], is a representative reactive technique in which a node suppresses its rebroadcast if all its neighbors are already covered by previous transmissions. SP incurs minimal overhead but often suffers from suboptimal pruning due to limited neighborhood knowledge. To address this limitation, Improved Self-Pruning (ISB) [17] incorporates extended neighborhood information to enhance pruning decisions. ISB achieves better performance than SP and DP by enabling more informed decisions without requiring forwarding lists. However, ISB relies on a degree-based pruning criterion, where nodes compare the number of neighbors to determine forwarding priority. This approach does not accurately reflect the actual coverage contribution of nodes, as a higher node degree does not necessarily imply better coverage of previously uncovered nodes.

Although both ExDP and ISB both exploit extended neighborhood information to improve broadcast efficiency, they differ fundamentally in their design philosophy. ExDP follows a proactive approach with explicit forwarding coordination, while ISB adopts a reactive strategy with local decision-making. Nevertheless, existing approaches do not explicitly consider the effective uncovered coverage contributed by neighboring nodes when making forwarding decisions. This limitation motivates the need for a more precise pruning mechanism that directly accounts for the actual coverage impact of nodes.

In this work, we address this gap by proposing a coverage-aware Enhanced Self-Pruning (ESP) algorithm, which combines the advantages of reactive decision-making with extended neighborhood knowledge. By utilizing 3-hop neighborhood information and incorporating a coverage-based pruning condition, ESP achieves more accurate forwarding decisions while maintaining low overhead.

3 Preliminaries

In this section, we describe the network model, broadcast assumptions, and notations used throughout the paper.

3.1 Network Model

We model the wireless ad hoc network as an undirected graph $G = (V, E)$, where V represents the set of nodes and E represents the set of communication links between nodes. An edge exists between two nodes if they are within each other's transmission range. All nodes are assumed to have identical transmission capabilities, resulting in symmetric links. For a node $v \in V$, let $N(v)$ denote the set of its 1-hop neighbors, defined as:

$$N(v) = \{u \in V | (u, v) \in E\}$$

In addition to 1-hop neighbors, each node is assumed to have access to extended neighborhood information up to 3 hops, obtained through periodic neighbor information exchange. This allows a node to estimate coverage beyond its immediate neighbors.

3.2 Broadcast Model

We consider a broadcast scenario in which a source node initiates the dissemination of a packet to all other nodes in the network. Upon receiving a broadcast packet for the first time, each node decides whether to rebroadcast the packet based on a pruning algorithm. Duplicate packets are discarded.

Let node u be the sender (parent) of a broadcast packet and node v be a receiver such that $v \in N(u)$. The objective of node v is to determine whether rebroadcasting the packet will contribute to covering additional nodes that have not yet received the message.

3.3 Coverage and Notation

To formalize the pruning process, we define the notion of uncovered neighbors. For a node v that receives a packet from node u, the initial set of uncovered neighbors is defined as: $U(u, v) = N(v) - N(u)$.

This set represents the neighbors of v that are not directly covered by the transmission of node u. In order to incorporate additional coverage information, let g denote the grandparent node of v, i.e., the node from which u received the packet. Since nodes in $N(g)$ are likely to have already received the broadcast, their coverage can also be excluded from consideration. Thus, the uncovered set can be further refined by removing neighbors of the grandparent node.

Furthermore, for any node $x \in N(u)$, we define its effective uncovered neighbor set with respect to u as: $N(x) - N(u)$. This represents the set of nodes that can be additionally covered by node x beyond the coverage already provided by node u. Similarly, the effective uncovered neighbors of node v are given by $N(v) - N(u)$.

These definitions form the basis for coverage-aware comparison in the proposed algorithm.

3.4 Problem Definition

The objective of the broadcast pruning algorithm is to minimize the number of forwarding nodes while ensuring that all nodes in the network receive the broadcast message. A node v should rebroadcast a packet only if it can cover at least one node that has not already been covered by previous transmissions.
The key challenge lies in accurately identifying whether a node contributes additional coverage, particularly in dense networks where significant overlap exists among neighbor sets. Existing approaches, such as ISB, rely on degree-based heuristics, which may not correctly capture this contribution. Therefore, a more precise coverage-aware mechanism is required to improve pruning efficiency.

4 Improved Self-Pruning(ISB) and Its Limitations

Improved Self-Pruning (Rab et al. [17]) is a reactive broadcast algorithm designed to reduce redundant transmissions without relying on explicit forwarding lists. Upon receiving a broadcast packet from a parent node u, a node $v \in N(u)$ determines whether to rebroadcast the packet based on its ability to cover additional nodes that have not yet received the message.
The pruning decision in ISB is based on the concept of uncovered neighbors. Initially, node v computes the set of neighbors that are not covered by the transmission of node u, defined as: $U(u, v) = N(v) - N(u)$. The goal of node v is to determine whether its rebroadcast can cover any nodes in $U(u, v)$. To further reduce redundancy, ISB considers the neighbors of node u, denoted by $x \in N(u)$, and removes from $U(u, v)$ the neighbors that are expected to be covered by such nodes.
Specifically, ISB applies a degree-based pruning rule: for each node $x \in N(u)$, the neighbor set $N(x)$ is removed from $U(u, v)$ if x is considered more *"capable"* than v in terms of coverage. This capability is determined based on node degree and node identifier.

4.1 ISB Pruning Condition

The pruning condition in ISB is defined as follows For each node $x \in N(u)$, node v removes $N(x)$ from $U(u, v)$ if: $|N(x)| > |N(v)|$ or $|N(x)| = |N(v)|$ and $id(x) < id(v)$.
After applying the above rule for all $x \in N(u)$, node v makes its forwarding decision as follows:

- if $U(u, v) = \emptyset$, node v drops the packet
- Otherwise, node v rebroadcasts the packet

This mechanism allows ISB to eliminate redundant forwarders while avoiding the use of explicit forwarding lists.

4.2 Limitation of Degree-Based Pruning

Although ISB improves upon basic self-pruning by utilizing extended neighborhood information, its pruning decision relies on node degree as a proxy for coverage capability. However, node degree does not necessarily reflect the actual contribution of a node in covering previously uncovered neighbors.
In particular, the condition $|N(x)| > |N(v)|$ compares the total number of neighbors of nodes x and v, without considering whether these neighbors overlap with the coverage already provided by node u. As a result, a node with a higher degree may still have a significant portion of its neighbors already covered by u, contributing little or no additional coverage.
Consequently, ISB may incorrectly remove nodes from $U(u, v)$ based on misleading degree comparisons. This can lead to two undesirable outcomes:

- **Premature pruning**, where a node that could cover uncovered neighbors is incorrectly suppressed
- **Redundant forwarding**, where nodes with limited additional coverage are unnecessarily retained

To better understand this limitation, consider two nodes x and v, both neighbors of node u as shown is Figure 1. Suppose node x has higher degree than node v, i.e., $|N(x)| > |N(v)|$, but most of its neighbors are already included in $N(u)$. In contrast, node v may have fewer neighbors overall, but a larger portion of its neighbors may lie outside $N(u)$, thereby contributing more effectively to covering previously uncovered nodes as shown in Figure 1.

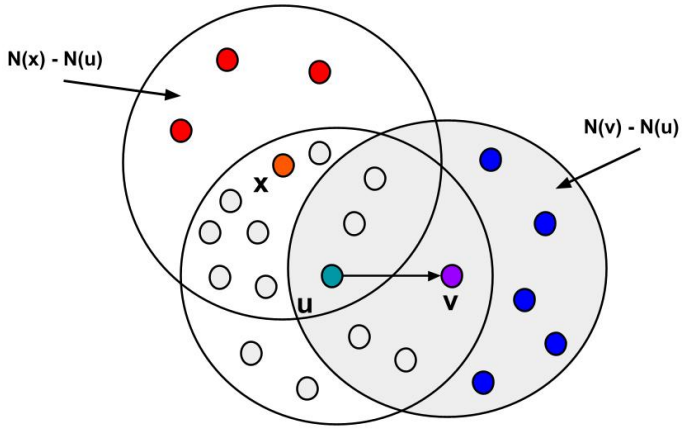


Fig. 1: Intuitive issue of ISB

In such scenario, ISB would favor node x over node v based solely on degree comparison, even though node v provides greater effective coverage. This mismatch between degree and actual coverage highlights a fundamental limitation of ISB.

5 Enhanced Self-Pruning (ESP)

The above observation in section 4 suggests that an effective pruning mechanism should not rely solely on node degree, but instead consider the *actual additional coverage* provided by a node beyond the coverage already achieved by previous transmissions. In other words, pruning decisions should be based on the ability of a node to cover *uncovered neighbors*, rather than its total number of neighbors. This motivates the design of a more precise, coverage-aware pruning strategy, which forms the basis of the proposed Enhanced Self-Pruning(ESP) algorithm. ESP also utilizes the extended 3-hop neighborhood information similar to ISB and additionally, incorporates lightweight grandparent information through packet piggybacking to further improve pruning accuracy.

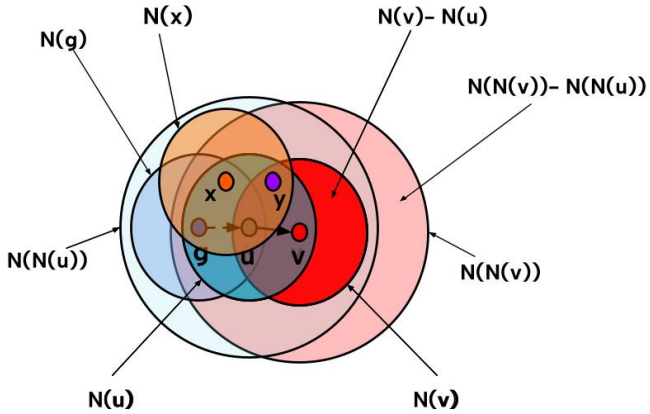


Fig. 2: Illustration of Enhnaced Self-Pruning

5.1 Coverage-Aware Pruning Condition

Let node v receive a broadcast packet from node u, and let $x \in N(u)$ be a neighbor of u. Instead of comparing node degrees, ESP compares the effective uncovered neighbors of nodes x and v with respect to u as shown in Figure 1.
The effective uncovered neighbor set of node v is defined as: $N(v) - N(u)$. Similarly, for node x, the effective uncovered neighbor set is: $N(x) - N(u)$.
The pruning condition is defined as follows:

$$|N(x) - N(u)| > |N(v) - N(u)| \tag{1}$$

or

$$|N(x) - N(u)| = |N(v) - N(u)| \text{ and } id(x) < id(v) \tag{2}$$

This condition ensures that pruning decisions are based on actual additional coverage rather than total node degree.

5.2 Refined Coverage Set Computation

Initially, node v computes its uncovered neighbor set as: $U(u, v) = N(v) - N(u)$. Let g denote the grandparent node of v, i.e., the node from which u received the packet as illustrated in Figure 2. Since nodes in $N(g)$ are likely to have already received the broadcast along with node u, ESP further refines the uncovered set as:

$$U(u, v) = N(v) - N(u) - N(g) \tag{3}$$

Then, for each node $x \in N(u)$ satisfying the coverage-aware pruning condition, ESP removes $N(x)$ from $U(u, v)$ as: $U(u, v) = U(u, v) - N(x)$.
Finally, node v decides whether to rebroadcast the packet based on whether the resulting set $U(u, v)$ is $\emptyset$ or not. Algorithm 1 shows how the proposed Enhanced Self-Pruning (ESP) operates:

Algorithm 1 Coverage-Aware Enhanced Self-Pruning based broadcast (ESP)

Precondition: Node v receives an unseen packet m from u; node u received the packet from grandparent node g
Require: $v, g \in N(u)$
$U(u, v) \leftarrow N(v) - N(u) - N(g)$
for each $x \in N(u)$ **do**
  if $|N(x) - N(u)| > |N(v) - N(u)|$ **then**
    $U(u, v) \leftarrow U(u, v) - N(x)$
  else if $|N(x) - N(u)| = |N(v) - N(u)|$ **and** $id(x) < id(v)$ **then**
    $U(u, v) \leftarrow U(u, v) - N(x)$
  end if
end for
if $U(u, v) = \emptyset$ **then**
  Drop the packet.
else
  Rebroadcast the packet.
end if

5.3 Complexity Analysis of ISB and ESP

The computational complexity of ESP is comparable to that of ISB. For each node v, the algorithm iterates over all neighbors of node u, resulting in a time complexity of $O(d^2)$, where d is the maximum node degree. The additional cost of computing set differences does not significantly increase the overall complexity.
In terms of communication overhead, ESP introduces minimal additional cost by piggybacking the grandparent node identifier in the broadcast packet. This overhead is negligible compared to the reduction in redundant transmissions achieved by improved pruning decisions.

6 Example Scenario

In this section we provide an example scenario to illustrate the benefit of using Enhanced Self-Pruning algorithm. For this, a sample network shown in Figure 3 is considered. The neighbor list of each node is illustrated in Table 1.

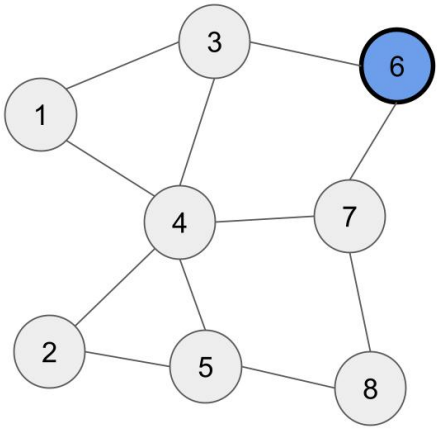


Fig. 3: A random topology of 8 nodes with source node 6 to show the improvements of the proposed method

Suppose, node 6 has initiated a broadcast. First of all, we will determine the list of forwarding nodes in Self-Pruning algorithm. From node 6, node 3 and 7 will receive the broadcast. After receiving the broadcast, node 3 will check if the set $N(3) - N(6)$ is $\emptyset$ or not. If the set is empty then it will not be a forwarding node, otherwise it will forward. Now, $N(6) = \{3, 6, 7\}$ and $N(3) = \{1, 3, 4, 6\}$, so, $N(3) - N(6) = \{1, 4\}$. As it is non-empty, node 3 will be a forwarding node. In the same way, for all other nodes we can sequentially determine which of the other nodes will be forwarding nodes. Table 1 and Table 2 show the complete analysis. After analysis, we can see that all the nodes except node 1 and 2 will forward the packet. Thus self-pruning will need 6 forwarding to complete the broadcast.

Now, let us see how Improved Self-Pruning will perform. The details results are shown in Table 3. It also takes total 5 nodes to forward the packet to cover the whole network similar to DP, including the original broadcast initiated by node 6.

For the Dominant Pruning algorithm the detail construction of U, B and F set is shown in Table 4. It takes total 5 nodes to forward the packet to cover the whole network, including the original broadcast initiated by node 6. For this network ExDP (Anannya et al. [18]) performs exactly similar to DP. The detail results are shown in Table 5.

Finally, we show the number of forwardings using the proposed Enhanced Self-Pruning algorithm (ESP). For ESP, as node 6 is the starting node, nodes {3,7} will get the packet with the single transmission from node 6. Then to decide whether node

3 will forward or not node 3 would calculate the set $U(6,3) = N(3) - N(6) - N(grandparent) = \{1,3,4,6\} - \{3,6,7\} - \emptyset = \{1,4\}$. From the set $U(6,3)$, now the neighbor of the nodes in $N(6)$ will be removed from $N(3)$, which satisfies the coverage-aware pruning condition as described in 5.1. With this conditions, we can see that there is no node which satisfies them. So, $U(6,3) = \{1,4\}$, which is non-empty. Thus, node 3 will be a forwarding node. Table 1 shows the complete analysis. We can see that, both ISB and ESP performs similar for this network, except for node 5. In ISB, node 5 will forward but in ESP, it will not forward. Thus, ISB requires total 5 nodes to forward the packet to cover the whole network, whereas ESP requires total 4 nodes to forward.

Finally to summarize, the SP requires 6 forwarding; ISB, DP and ExDP all will incur 5 forwardings each to complete the broadcast in the example scenario of Figure 3. But ESP requires only 4 forwardings which is also the optimum number of broadcast requires for this network, because if only nodes 6,3,7 and 4 forward the packet then all the nodes in the network would receive the packet. Thus, the Enhanced Self-Pruning exhibits the best performance among all the algorithms we discussed, giving equal forwardings compared to the optimal.

v	$N(v)$	$N(N(v))$
1	1,3,4	1,2,3,4,5,6,7
2	2,4,5	1,2,3,4,5,7,8
3	1,3,4,6	1,2,3,4,5,6,7
4	1,2,3,4,5,7	1,2,3,4,5,6,7,8
5	2,3,5,8	1,2,3,4,5,7,8
6	3,6,7	1,3,4,6,7,8
7	4,6,7,8	1,2,3,4,5,6,7,8
8	5,7,8	2,4,5,6,7,8

Table 1: 1-hop and 2-hop Neighbors of Each Node

u	v	$N(v) - N(u)$	*Forward?*
$\emptyset$	6	{3,6,7}	Yes
6	3	$N(3) - N(6) = \{1,4\}$	Yes
6	7	$N(7) - N(6) = \{4,8\}$	Yes
3	1	$N(1) - N(3) = \emptyset$	No
3	4	$N(4) - N(3) = \{2,5,7\}$	Yes
7	8	$N(8) - N(7) = \{5\}$	Yes
4	2	$N(2) - N(4) = \emptyset$	No
4	5	$N(5) - N(4) = \{8\}$	Yes

Table 2: Detail Analysis of SP for the scenario in Figure 3

u	v	$U(u,v)$	$Forward?$
$\emptyset$	6	{3,6,7}	Yes
6	3	$N(3) - N(6) = \{1,4\}$	Yes
6	7	$N(7) - N(6) - N(3) = \{8\}$	Yes
3	1	$N(1) - N(3) = \emptyset$	No
3	4	$N(4) - N(3) = \{2,5,7\}$	Yes
7	8	$N(8) - N(7) - N(4) = \emptyset$	No
4	2	$N(2) - N(4) = \emptyset$	No
4	5	$N(5) - N(4) = \{8\}$	Yes

Table 3: Detail Analysis of ISB for the scenario in Figure 3

u	v	U_v	B_v	$F(v)$
$\emptyset$	6	{1,4,8}	{3,7}	{3,7}
6	3	{2,5}	{1, 4}	{4}
6	7	{1,2,5}	{4,8}	{4}
3	4	{8}	{2,5,7}	{5}
4	5	$\emptyset$	{8}	$\emptyset$

Table 4: Detail Analysis of DP for the scenario in Figure 3

u	v	Q_v	U_v	B_v	$F(v)$
$\emptyset$	6	$\emptyset$	{1,4,8}	{3,7}	{3,7}
6	3	$\emptyset$	{2,5}	{1, 4}	{4}
6	7	$\emptyset$	{1,2,5}	{4,8}	{4}
3	4	$\emptyset$	{8}	{2,5,7}	{5}
4	5	$\emptyset$	$\emptyset$	{8}	$\emptyset$

Table 5: Detail Analysis of ExDP for the scenario in Figure 3

u	v	g	$U(u,v)$	$Forward?$
$\emptyset$	6	$\emptyset$	{3,6,7}	Yes
6	3	$\emptyset$	$N(3) - N(6) = \{1,4\}$	Yes
6	7	$\emptyset$	$N(7) - N(6) - N(3) = \{8\}$	Yes
3	1	6	$N(1) - N(3) - N(6) = \emptyset$	No
3	4	6	$N(4) - N(3) - N(6) = \{2,5\}$	Yes
7	8	6	$N(8) - N(7) - N(6) - N(4) = \emptyset$	No
4	2	3	$N(2) - N(4) - N(3) = \emptyset$	No
4	5	3	$N(5) - N(4) - N(3) - N(7) = \emptyset$	No

Table 6: Detail Analysis of ESP for the scenario in Figure 3

7 Experimental Setup

In this section, we describe the simulation environment, network configuration, and evaluation metrics used to assess the performance of the proposed Enhanced Self-Pruning (ESP) algorithm. For fair comparison, we closely follow the experimental setup used in the Improved Self-Pruning (ISB) study [17]. The parameters and their values used in the experiment are summarized in Table 7. Total ten different scenarios were generated for each case and an average is taken. The simulation code was built using Java programming language.

Parameter	Value
Number of nodes	100 (Sparse Network) 350 (Moderately Dense Network) 500 (Dense Network)
Area	625m x 625m
Transmission range	125m-225m

Table 7: Parameters Used in Experiments

8 Experimental Results

To show the effectiveness of the ESP, we implement the algorithm along with the SP, ISB, DP and ExDP algorithms through some simulation experiments carried out in random networks. The primary performance metric used in this study is the number of forwarding nodes, which directly reflects the efficiency of the broadcast algorithm. A lower number of forwarding nodes indicates reduced redundancy and improved performance. In addition, we also evaluate the communication overhead between the DP, ExDP and ESP algorithms using the following metrics:

- **Average packet overhead:** This metric measures the average number of control bytes carried per broadcast packet. It is defined as:

$$\text{Average Packet Overhead} = \frac{1}{N_{packets}} \sum_{i=1}^{N_{packets}} O_i \tag{4}$$

  where O_i denotes the overhead associated with the i-th packet, and $N_{packets}$ is the total number of transmitted packets.
- **Total control overhead:** This metric represents the cumulative overhead incurred during the broadcast process:

$$\text{Total Control Overhead} = \sum_{i=1}^{N_{packets}} O_i \tag{5}$$

  This metric captures the overall communication cost introduced by the algorithm.

Finally, we also carried out a theoretical comparison analysis of energy consumption for both ExDP [18] and ESP algorithm based on the experimental results achieved. All simulations ensure complete broadcast coverage, i.e., all nodes in the network successfully receive the broadcast packet.

8.1 Number of Forwardings Required

In this section, we evaluate the performance of the proposed Enhanced Self-Pruning (ESP) algorithm and compare it with SP, DP, ISB, and ExDP under various network configurations. The results are presented in terms of forwarding node reduction.

8.1.1 Performance in Sparse Networks

We first analyze the performance of the algorithms in sparse networks consisting of 100 nodes. Figure 4 shows the number of forwarding nodes as a function of transmission range.

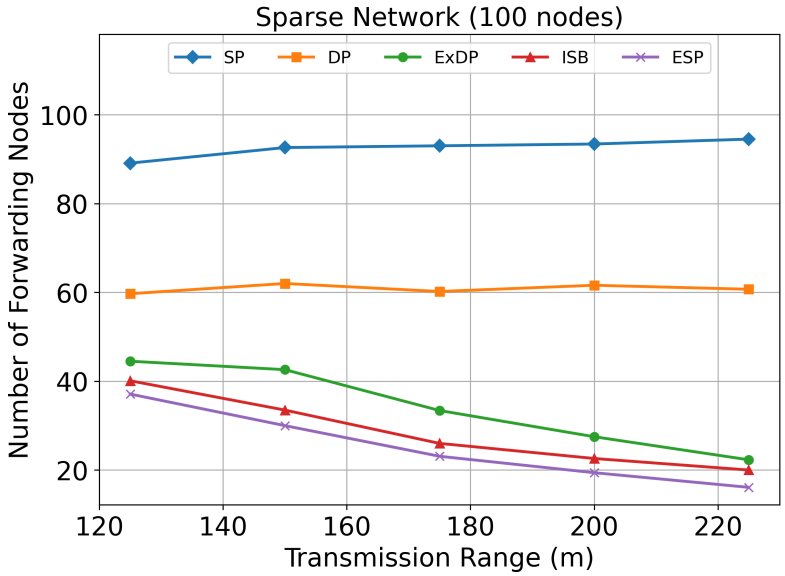


Fig. 4: Number of forwarding nodes vs. transmission range in sparse network (100 nodes).

As shown in the figure, ESP consistently outperforms ISB,SP,DP and ExDP across all transmission ranges. The improvement becomes more noticeable as the transmission range increases, where ESP achieves a significant reduction in forwarding nodes. Although, ISB and ExDP also performs well due to its extended neighborhood knowledge, ESP is able to achieve comparable or better performance while maintaining a reactive decision process.

8.1.2 Performance in Moderately Dense Networks

Next, we consider a moderately dense network with 350 nodes. The results are presented in Figure 5. In this scenario, the advantage of ESP becomes more pronounced. The gap between ESP and ISB increases with network density, demonstrating the effectiveness of coverage-aware pruning in environments with higher node connectivity. Compared to ExDP, ESP achieves competitive performance despite relying on a reactive approach without explicit forwarding coordination.

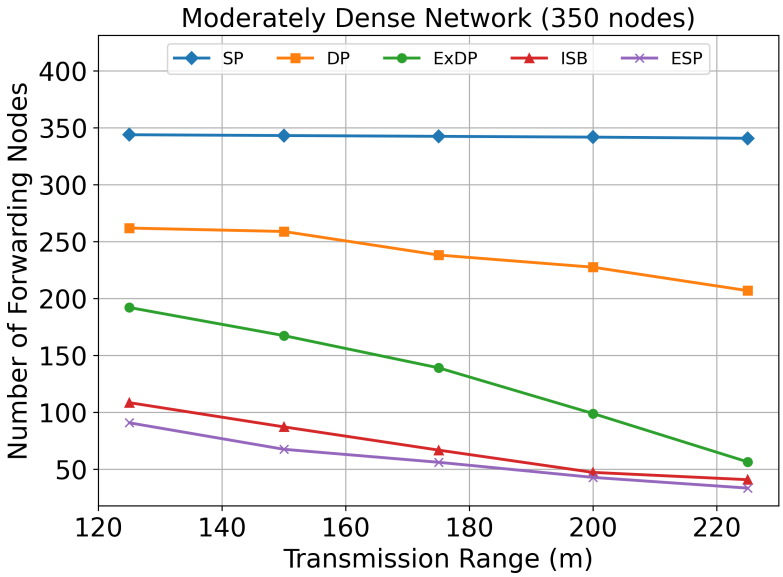


Fig. 5: Number of forwarding nodes vs. transmission range in moderately dense network (350 nodes).

8.1.3 Performance in Dense Networks

We further evaluate the algorithms in dense networks consisting of 500 nodes. Figure 6 illustrates the results.

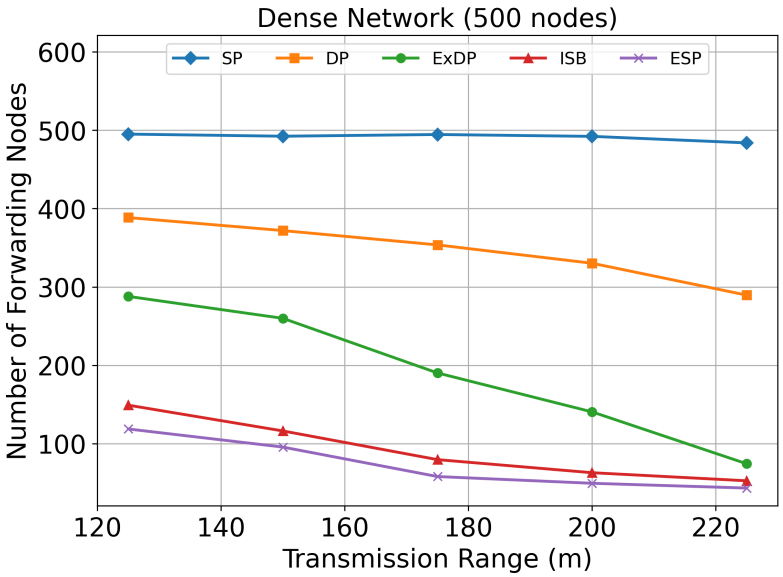


Fig. 6: Number of forwarding nodes vs. transmission range in dense network (500 nodes).

In dense networks, ESP achieves the highest reduction in forwarding nodes among all compared methods. The improvement over ISB becomes substantial, reaching up to approximately 20–25% in high transmission ranges. This demonstrates that ESP effectively mitigates redundant transmissions by accurately identifying nodes with meaningful coverage contributions. Moreover, ESP outperforms both ISB and ExDP, indicating that coverage-aware pruning can be more effective than increasing neighborhood knowledge alone.

8.1.4 Impact of Node Density

To further analyze scalability, we examine the effect of increasing node density while keeping the transmission range fixed. The results are shown in Figure 7. As the number of nodes increases, the number of forwarding nodes also increases for all algorithms. However, ESP exhibits a slower growth rate compared to all other algorithms, demonstrating better scalability. This behavior is attributed to the more precise pruning decisions enabled by coverage-aware comparison.

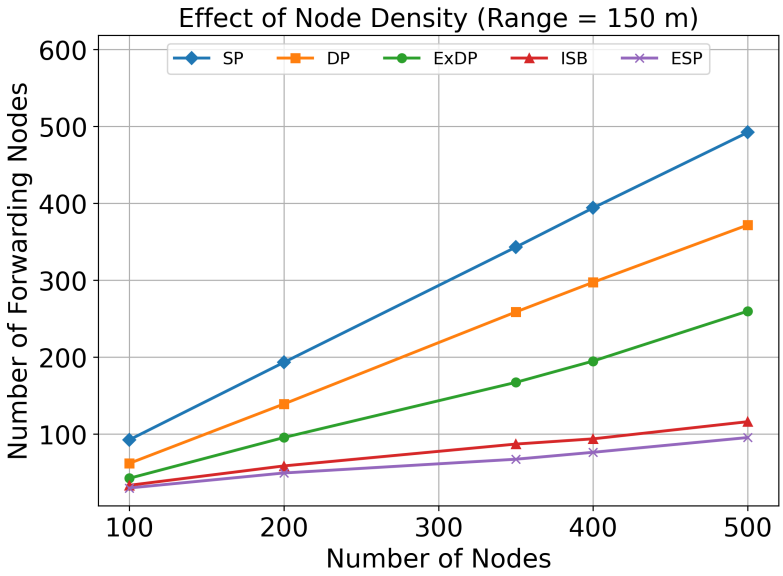


Fig. 7: Number of forwarding nodes vs. node density (fixed transmission range).

8.2 Overhead Analysis

The ESP algorithm introduces a small additional overhead by piggybacking the grandparent node identifier in each broadcast packet. Compared to proactive approaches such as DP [16] and ExDP [18], which include forwarding node lists or require extended coordination, the overhead introduced by ESP is minimal.

Let H_{base} denote the header size of a standard broadcast packet. In ESP, the header size becomes:

$$H_{ESP} = H_{base} + H_{gp} \tag{6}$$

where H_{gp} represents the size of the grandparent node identifier.

Since H_{gp} is constant and typically small, the increase in per-packet overhead is negligible. However, ESP significantly reduces the number of forwarding nodes, which in turn reduces the total number of transmitted packets.

The overall efficiency of a broadcast algorithm depends on the trade-off between per-packet overhead and the total number of transmissions. While ESP introduces a slight increase in packet size, it reduces the number of rebroadcasts through more accurate pruning decisions. As a result, the total control overhead can be expressed as:

$$\text{Total Overhead} \propto N_{forward} \times H_{packet} \tag{7}$$

where $N_{forward}$ is the number of forwarding nodes and H_{packet} is the packet header size.

Since ESP achieves a significant reduction in $N_{forward}$, the overall control overhead is reduced despite the marginal increase in H_{packet}.

Now let us see the communication overhead associated with DP, ExDP and ESP algorithms.

Figure 8 shows the average packet overhead. ESP introduces a slight increase in packet overhead due to the inclusion of grandparent information. However, this increase is minimal compared to proactive approaches such as DP and ExDP.

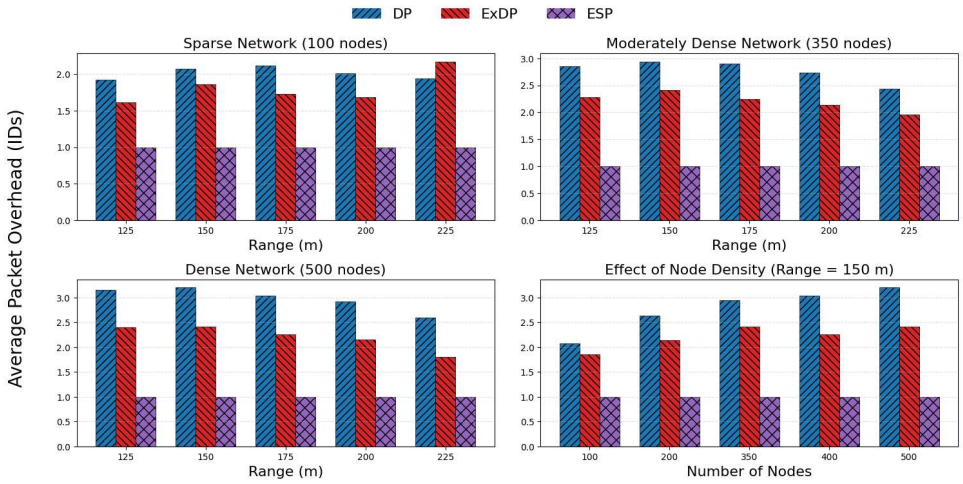


Fig. 8: Average packet overhead comparison.

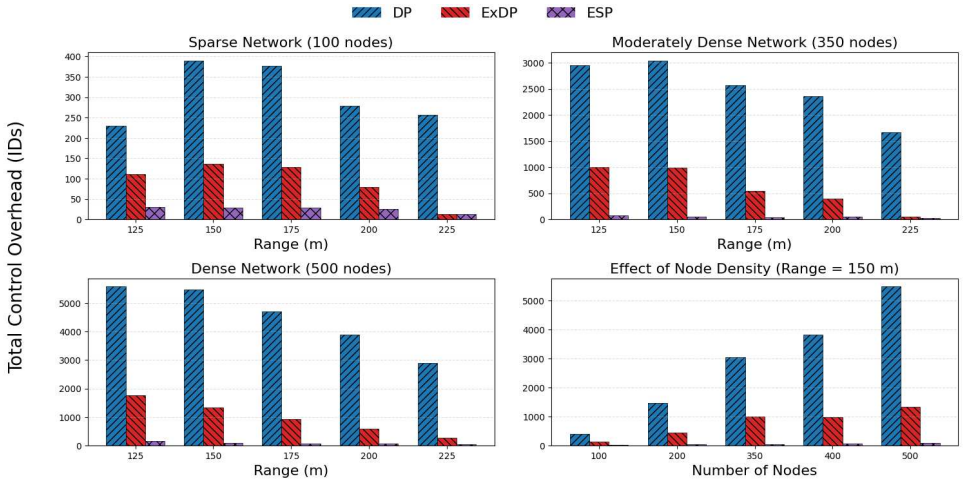


Fig. 9: Total control overhead comparison.

Figure 9 presents the total control overhead. Despite the marginal increase in per-packet overhead, ESP significantly reduces the total control overhead by decreasing the number of forwarding nodes compared to the proactive approaches like DP and ExDP.

8.3 Energy Consumption Analysis of ESP and ExDP

In a wireless ad hoc network the hosts are power constrained devices with limited energy and their power should be used in an efficient way. There are 2 sectors where the energy consumption will occur and those are:

1. Energy consumption due to *HELLO* packet propagation
2. Energy consumption due to *DATA* packet broadcasting

8.3.1 Energy Consumption for *HELLO* packet propagation

In both ESP and ExDP, the total energy required for propagating *HELLO* packets is the same because both uses the same extended 3-hop neighborhood information. Now, suppose n is the total number of nodes in the network. For a single round the total number of *HELLO* packet transmissions,T_{HELLO} and the total number of hello packet receptions R_{HELLO} in both ESP and ExDP can be stated as follows:

$$T_{HELLO} = \sum_{u=1}^{n}(1 + |N(u)| + |[N^2(u) - N(u)]|) \tag{8}$$

$$R_{HELLO} = \sum_{u=1}^{n}(|N^3(u)|) \tag{9}$$

Now, the total energy of a network is calculated as the summation of the total energy to transmit a packet in the network, E_T and the total energy for receiving the packet, E_R. Total energy can be stated as:

$$E_{HELLO} = E_{T_{HELLO}} + E_{R_{HELLO}} \tag{10}$$

Now, since both ESP and ExDP uses the same extended 3-hop neighborhood information: $E_{HELLO(ESP)} = E_{HELLO(ExDP)}$.

8.3.2 Energy Consumption for *DATA* packet broadcasting

Suppose, total p nodes will forward in ExDP and q nodes will forward in ESP, among all the nodes n in the network. The list of forwarding nodes for ExDP is, $\mathcal{F}_{ExDP} = \{f_1, f_2, f_3, \ldots, f_p\}$ and the list for ESP is $\mathcal{F}_{ESP} = \{f_1, f_2, f_3, \ldots, f_q\}$. Thus, if P_t and P_r is power required to transmit a packet by a node and power required to receive a packet by a node respectively, $E_{T_{DATA}}$ to transmit a broadcasting packet for $ExDP$ is defined as:

$$E_{T_{DATA(ExDP)}} = |\mathcal{F}_{ExDP}| \times P_t \times t \tag{11}$$

Similarly for ESP, the corresponding $E_{T_{DATA}}$ is defined as:

$$E_{T_{DATA(ESP)}} = |\mathcal{F}_{ESP}| \times P_t \times t \tag{12}$$

Now, since the reachablitly for both $ExDP$ and ESP is 100%, the $E_{R_{DATA}}$ for both $ExDP$ and ESP are same and defined as follows:

$$E_{R_{DATA}} = n \times P_r \times t \tag{13}$$

Therefore, the total energy required to broadcast a $DATA$ packet using both $ExDP$ and ESP are defined as:

$$E_{DATA(ExDP)} = E_{T_{DATA(ESP)}} + E_{R_{DATA}} \tag{14}$$

$$E_{DATA(ESP)} = E_{T_{DATA(ESP)}} + E_{R_{DATA}} \tag{15}$$

Now, experimental results in section 8 shows that $|\mathcal{F}_{ESP}| < |\mathcal{F}_{ExDP}|$ consistently, therefore it is clear that $E_{DATA(ESP)} < E_{DATA(ExDP)}$. Thus, it is easily understandable that, ESP will reduce energy consumption of the whole network to a great extent compared to ExDP [18].

9 Conclusion and Future Work

In this paper, we proposed an Enhanced Self-Pruning (ESP) algorithm for efficient broadcasting in multi-hop wireless ad hoc networks. Unlike existing self-pruning approaches, ESP introduces a coverage-aware pruning mechanism that evaluates the effective contribution of nodes based on uncovered neighbor sets rather than relying on node degree. In addition, ESP incorporates lightweight grandparent information through packet piggybacking and utilizes extended 3-hop neighborhood knowledge to further refine pruning decisions. Extensive simulation results demonstrate that ESP significantly reduces the number of forwarding nodes compared to SP, ISB, DP and ExDP across a wide range of network densities and transmission ranges. In particular, ESP achieves up to 20–25% reduction in dense network scenarios. Furthermore, ESP consistently outperforms the ExDP algorithm while maintaining a reactive decision framework, thereby avoiding the overhead associated with explicit forwarding coordination and also reducing the total energy consumption.

A comprehensive overhead analysis shows that the additional control information introduced by ESP is minimal and is effectively compensated by the reduction in redundant transmissions. As a result, ESP achieves lower total control overhead and improved efficiency in broadcast dissemination. Overall, the proposed ESP algorithm demonstrates that coverage-aware pruning combined with extended neighborhood knowledge provides a scalable and effective solution to the broadcast storm problem.

As part of future work, the proposed approach can be extended to dynamic and mobile network environments, where node mobility and link instability may further impact broadcast performance. Additionally, incorporating probabilistic link models and adaptive pruning strategies could further enhance robustness and efficiency.

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