# Extended Neighborhood Knowledge based Dominant Pruning (ExDP)

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***Abstract*—Reducing number of forwarding nodes is the primary objective when broadcasting the same message to all the nodes in a multi-hop wireless network. Without proper measures broadcasting may result in many redundant (re)transmissions. The prominent Dominant Pruning (DP) algorithm reduces re-transmissions to some extent using only 2-hop neighbor information of each node. Further reduction is possible if a node is equipped with three or more hops' neighborhood information. In this paper, we propose a new broadcasting technique dubbed as "ExDP" which uses extended 3-hop neighborhood information of each node in order to reduce redundancy. Expanding neighborhood knowledge up to three hops enables a forwarding node to detect which other nodes in the previous node's forwarding list are going to cover some of its 2-hop neighbors and eliminate those from reconsideration. We verify the efficacy of the proposed protocol with rigorous simulation results. The experimental results show that the proposed protocol outperforms the dominant pruning algorithm in reducing broadcast redundancy. Although collecting 3-hop neighborhood information requires some extra overhead, the additional cost is amortized over large data packets as number of re-transmissions of data packets is significantly reduced in the proposed technique.**

***Index Terms*—Broadcasting, Pruning, Wireless Ad Hoc Network, Neighborhood Information, Power Consumption.**

## I. Introduction

Wireless mobile hosts can communicate with each other by forming an ad hoc network when network infrastructure is unavailable or costly to build. A wireless ad hoc network is temporarily deployed for "ad hoc" purposes and works without any centralized control. If the destination node is out of the transmission range of the source, then the source needs to rely on intermediate nodes to forward the packet to the destination. The intermediate nodes act as routers to forward the packet and they have to take decisions about the path through which the packet should be forwarded.

The mobile nodes are resource constrained devices with limited energy and power. If these node‘s power is not used in an organized way, the outcome could be devastating: it could lead to even network partitions. Another concern about wireless ad hoc network is, it‘s topology is constantly changing due to very high node mobility. Despite mobility, wireless ad hoc networks needs to broadcast messages for various services such as route discovery, periodic data dissemination, erasing an invalid route, locating a node, duplicate IP address detection or sending alarm signals in the entire network and even for sending actual data packets [1].

The simplest way to achieve broadcasting is blind flooding. Blind flooding results in redundant transmissions, high energy consumption and finally leads to broadcast storm problem [2]. Various methods have been proposed to broadcast a message to the network to reduce redundancy.These attempts can be mainly classified into two categories:–(i) reactive, and (ii) proactive. In reactive approach, upon receiving a packet, a node decides itself whether to forward the packet or not. In a proactive scheme, a node selects a subset of nodes from it‘s neighbors as forwarding nodes and append this information into the packet header. One of the effective proactive schemes is Dominant Pruning (DP) algorithm which uses 2-hop neighbor connectivity information of each node. Partial Dominant Pruning (PDP) and Total Dominant Pruning (TDP) are two variants of DP which uses neighborhood information more effectively to produce less number of forwarding nodes.

Although DP and its variants (PDP and TDP) reduce retransmissions to some extent, further optimization is possible if nodes are provided with extended neighborhood information. In this paper, we propose a new approach called *Extended Neighborhood Information based Dominant Pruning (ExDP)* to reduce redundancy more by exploiting 3-hop neighborhood information of each node in the network. The key idea behind further optimization is DP, PDP and TDP only uses the information about the nodes that have already been covered by the previous node (i.e., by the node from which it received the broadcast for forwarding). But if a node uses the information about the nodes that are going to be covered by other nodes present in the forwarding list created by the previous node even further optimization is possible. This would result in further reduction in its own forwarding list and subsequent nodes' forwarding lists down the chain of the broadcast. The overhead associated with collecting additional neighborhood information is amortized over large broadcast packets as number of re-transmissions of the broadcast packets is significantly reduced in the proposed technique. The performance of the proposed technique has been evaluated using extensive simulations. Simulation results show that the proposed methodology outperforms DP and its variants PDP and TDP in terms of number of packet forwarding and energy consumption.

The rest of the paper is organized as follows: Section II presents brief literature review. Section III defines the terminologies used in this paper. Section IV presents the algorithm and shows an example scenario to show the differences between state-of-the-art methods and the proposed one. Section V reports experimental results. Finally, Section VI depicts the attainments of this method and concludes the paper with some pointers for possible future works.

## II. Related Works

In recent years, a number of broadcasting techniques has been proposed. The most simplistic approach *blind flooding* results in lots of redundant transmissions within a network [2].

To solve the problem, authors suggested controlled flooding [3], probabilistic forwarding schemes [4], counter-based schemes [5], distance and/or location aided schemes [6]–[8], cluster-based schemes [9], [10] and neighbor knowledge schemes [11]–[19].

Finding the most optimized broadcast tree is NP-complete [11] as this is similar to finding minimum connected dominating sets (MCDS) [20]. Lim and Kim [11] proposed a reactive algorithm called Self Pruning (SP) where a node decides itself whether to forward a packet upon receiving if some of its neighbors are not covered by the previous transmission. In Scalable Broadcast Algorithm (SBA) [21], instead of considering only *the previous* transmission, a node does not rebroadcast the packet if all of its neighbors have received the packet from all previous transmissions. In Improved self pruning [22], each node makes decision whether to forward or not based on extended 2-hop neighbor information.

Lim and Kim proposed another algorithm [11], called Dominant Pruning (DP). In DP, a node proactively creates a subset of its neighbors who would further forward the packet to cover all the nodes that are exactly 2-hops away. When a node receives a packet if its id is mentioned in the forward list then it would create its own forward list from its 1-hop neighbors using the same algorithm. Authors in [12], 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. In [16], the authors proposed Enhanced Partial Dominant Pruning (EPDP) which is an extension of PDP. It takes advantage of the fact that the same node may hear the same packet several times from its neighbors and after receiving packet from other neighbors the node updates its uncovered set. Rahman et al. [23] extend the Dominant Pruning (DP) algorithm to work in un-trusted environment. Authors in [15] showed that, DP not considering the common neighbors of sender and receiver for forwarding sometimes leads to incorrect result for particular topologies. However, even if the shared nodes are not considered as the candidate nodes for being in the forward list, the authors in [11] ensured that DP covers all the nodes in the network.

Similar to DP, Multipoint Relaying (MPR) [13] uses 2-hop neighbor information to reduce broadcast redundancy. Ad-Hoc Broadcast Protocol (AHBP) [24] uses 2-hop neighbor information as well as the history of the route the packet has traversed. According to [25], the relative degree of a node is used to make decision whether a node should be included in the forward list or not. The relative degree of a node is denoted as the number of neighbors of a node those have not received the broadcast packet from earlier iterations. Dhan and Rieck proposed another method called $k$-Shortest Path Pruning ($k$-SPP) algorithm in [18]. In this method, each node must maintain an awareness of it's $k+1$ hop neighbors and also the broadcast packet carries IDs of the most recent $k$ nodes it has visited. In [26], authors suggested a technique for communicating among nodes in a wireless sensor network name "Smart Gossip". It is actually a combination of probabilistic approach and neighbor connectivity approach. In this approach, each node forwards a message with a probability, $p_{\text{gossip}}$ and selects the value of $p_{\text{gossip}}$ by overhearing the messages by neighbors. In [27], Three-Hop Horizon Pruning (THP) is proposed which uses 3-hop neighborhood information and creates forwarding list to cover all the nodes that are exactly 3-hop away.

The proposed technique, ExDP also uses 3-hop neighbor information while making decisions but it restricts itself only to cover 2-hop neighbors of each node. The redundant transmissions are reduced to a great extent at the cost of little additional overhead.

## III. Preliminaries

We model a wireless ad hoc network as a simple undirected graph $G(V,E)$ where $V$ is the set of all vertices (mobile hosts) in the network and $E$ is the set of all edges in the network. An edge between two nodes indicates that they are within the transmission range of each other and this relation is assumed to be symmetric. Let $N(v)$ is the set of all 1-hop neighbors of node $v$. The nodes that are in the transmission range of $v$ are member of this set and $N(N(v))$ is the set of all nodes within 2-hops of node $v$.

### A. The Dominant Pruning (DP) Algorithm

Suppose, a node $v$, receives a packet from node $u$ (source) and is selected as a forwarder. Thus, node $v$ needs to construct it's own $U_{\text{v}}$ set, which is the set of nodes that need to be covered by using nodes from $B_{\text{v}}$ set. $B_{\text{v}}$ is the set of one hop neighbors of node $v$ that are eligible to be included in the forwarding list. Now, in DP, node $v$ selects some nodes from $N(v)$ to cover the nodes in $N(N(v))$. Among the nodes in $N(N(v))$, $v$ and $N(u)$ have already received the packet. $N(v)$ will receive the packet when $v$ will forward. Thus, $v$ will select nodes in forwarding list to cover only the nodes in $U_{\text{v}} = N(N(v)) - N(v) - N(u)$ from $B_{\text{v}} = N(v) - N(u)$, as nodes in $N(u)$ have already been considered by node $u$. Node $v$ creates forward list, $F(v) = \{f_1, f_2, ..., f_i\}$ such that $F(v) \subseteq B_v$. This forward list is piggybacked with the broadcast packet. In the selection process of forwarding nodes from $B_{\text{v}}$, node $v$ selects a node $w \subseteq B_{\text{v}}$ which has maximum number of uncovered nodes as its neighbors. This node $w$ is included in $F_v$ and $U_\text{v}$ becomes $U_\text{v} - N(w)$ and $B_\text{v}$ becomes $B_\text{v} - \{w\}$. This process is continued until all the nodes in $U_\text{v}$ is covered or $F_v$ does not grow further. As finding a minimum set of forwarding node is NP-Complete, here a greedy set cover algorithm is used. In the selection process node $v_\text{k}$ is selected with the maximum number of uncovered neighbor nodes. The algorithm for selection process of DP [11] is given below:

**Algorithm 1 Selection Process of Dominant Pruning (DP) to find forward list, F**:

1: Let $F = \emptyset$, $K = \{S_1, S_2, ..., S_n\}$ where $S_k = N(v_k) \cap U (1 \leq k \leq n)$, $Z = \emptyset$.
2: Find the set $S_k$ whose size is maximal in the set K.
3: $F = F \cup v_k$, $Z = Z \cup S_k$, $K = K - S_k$, $S_l = S_l - S_k$ for all $S_l \in K$.
4: If $Z = U$, then complete the algorithm.
5: Otherwise, repeat from 2 again.

The same selection process mentioned above have been used by PDP, TDP and the proposed ExDP.

### *B. The Partial Dominant Pruning (PDP) Algorithm*

In [12], authors proposed PDP which uses 2-hop neighbor connectivity information and is able to deduce more nodes from $U_v = N(N(v)) - N(v) - N(u)$. The nodes that can be excluded from set $U_\text{v}$ are the neighbors of $N(u) \cap N(v)$. As these nodes are exactly 2-hop away from the previous node $u$, and node $u$ has already selected nodes from $N(u)$ to cover them. These nodes are included in $P$ set, such that, $P = N(N(u) \cap N(v))$. Therefore, $U_\text{v}$ set is redefined in PDP as $U_v = N(N(v)) - N(v) - N(u) - P$.

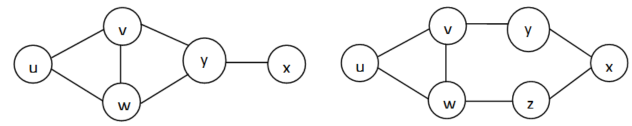
### *C. The Total Dominant Pruning (TDP) Algorithm*

TDP requires more information than DP and PDP. As we are assuming $u$ is sending the packet to node v, it means, u has already computed $F(u)$ set in a way that all the nodes in $N(N(u))$ are covered. If node $v$ can receive the $N(N(u))$ information with the broadcast packet, it will be able to reduce the size of $U_\text{v}$ set. Therefore, the 2-hop away neighbor set $U_\text{v}$ that needs to be covered by $F(v)$ becomes $N(N(v)) - N(N(u))$. We can see, actually partial 3-hop node information is used to reduce the size of $U_\text{v}$.

## IV. The Proposed Methodology

### *A. Extended Neighbor Information Based Dominant Pruning (ExDP) Algorithm*

The proposed method dubbed as Extended Neighbor Information Based Dominant Pruning (ExDP) falls into the category of proactive broadcast scheme which reduces redundant broadcast packets by using 3-hop neighbor connectivity information of a node. This can be achieved by forwarding the periodic beacon messages with a time-to-live (TTL) field set to three. In wireless networks a node usually sends HELLO messages to all its neighbors to indicate it's presence. We just need to propagate the beacon messages up to 3-hops instead of 1-hop. Although there will be some delay while propagating HELLO packets up to 3-hop neighbors, we assume that the delay is not significant compared to frequency of broadcast messages. If the size of $U_\text{v}$ is less, then the number of forwarding list also becomes fewer. This size of $U_\text{v}$ is less in PDP and TDP compared to DP. Actually, $(size\ of\ (U_v))_{TDP} \leq (size\ of\ (U_v))_{PDP} \leq (size\ of\ (U_v))_{DP}$. In ExDP, each node uses its complete 3-hop neighbor information to reduce the size of $U_v$ set further.




(a) (b)

Fig. 1: Sample Scenarios

Suppose, a node $u$ (source) initiates a broadcast packet and all the nodes in the transmission area of node $u$ receive the packet. Assume, node $v$ and node $w$ are selected as forwarders by node $u$. As each node has complete 3-hop neighbor information, a forwarding node $v$ has knowledge about the 2-hop away neighbors of node u, which is denoted as $N(N(u))$. Thus $U_\text{v}$ of node $v$ becomes $N(N(v)) - N(N(u))$. Now, there might be some nodes which are included in $U_\text{v}$ that are neighbors of one or more nodes in the forward list of $u$. In Fig. 1, two such scenarios are presented. Node $v$ and $w$ both will include node $x$ in their uncovered set as node $x$ is exactly 2-hop away from them. Node $v$ and $w$ both will include node $y$ for forwarding so that node $x$ in Fig. 1(a) is covered. Although node $y$ is included twice to forward in DP algorithm, it would forward only once and no redundant transmission occurs here. For Fig. 1(b), both node $y$ and $z$ will forward the message and both will cover node $x$. It is clearly seen, that only one re-transmission is enough (either node $y$ or node $z$) to cover node $x$. It happens because in DP, the forwarding nodes forward packet without any co-ordination among themselves. This redundant transmission is avoided by using the proposed ExDP protocol. To achieve this, the nodes in the forward list does not need to have any extra communication among themselves, the nodes simply requires 3-hop neighborhood information.

If a node $w$ which is a neighbor of node $v$ also appears in the forward list $F(u)$ (and ID of node $w$ is smaller than ID of node $v$), then using 3-hop neighbor information $v$ can easily determine $N(N(w))$ set as $N(N(w)) \subseteq N(N(N(v)))$, which are neighbors of node $v$ that are 3-hops away. Thus, $v$ can come to a decision that $N(N(w))$ are going to be covered by $w$ when it forwards and it can subtract $N(N(w))$ from its uncovered set $U_\text{v}$. Thus, only one node between $y$ and $z$ will forward the packet. Fig. 2 highlights the overall idea. From the figure, it is easy to see that if there exists a node $x$ which is exactly 2-hop away from both $v$ and $w$ [if, $x \in N(N(v)) - N(v)$ and $x \in N(N(w)) - N(w)$], then either node $v$ or node $w$ will include node $x$ in $U$ list. Which one from node $v$ and $w$ will cover node $x$ depends on their ID.

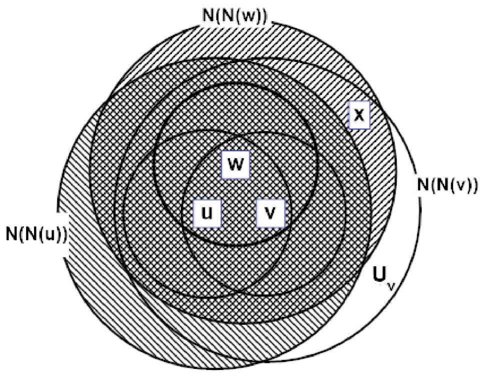



Fig. 2: Illustrating ExDP algorithm

Formally, let, $F(u) = \{f_1, f_2.., f_m\}$, then another set $Q_{\text{v}}$ of node $v$ [$v \in F(u)$] can be calculated by the following equation-

$$Q_v = \bigcup_{i=1}^{|F(u)|} N(N(f_i)) \textbf{ where } ID(f_i) < ID(v) \textbf{ and } f_i \in F(u) \cap N(v) \quad (1)$$

Thus, the final equation of $U_{\text{v}}$ becomes:

$$U_v = N(N(v)) - N(N(u)) - Q_v \quad (2)$$

Algorithm of proposed Extended Neighbor Information based Dominant Pruning (ExDP) operates as follows:

**Algorithm 2 Extended Neighbor Information based Dominant Pruning (ExDP) Algorithm**:

1: Node $v$ has received a packet from node $u$. If it has not seen the packet and $v$ is in the forward list of $u$, $F(u)$ then it proceeds to step 2, otherwise discards it.

2: Let $F(u) = \{f_1, f_2.., f_m\}$, $v \in F(u)$ and $Q_v = \emptyset$.

3: For each $f_i \in F(u)$, if ID of $f_{\text{i}}$ is smaller than ID of node $v$ and $f_i \in N(v)$, then node $v$ constructs $Q_{\text{v}}$ as follows,

$$Q_v = Q_v \bigcup N(N(f_i)) \quad (3)$$

4: Now node $v$ uses $N(N(v))$, $N(N(u))$, $N(u)$, and $Q_{\text{v}}$ to obtain $U_{\text{v}}$ and $B_{\text{v}}$.

$$U_v = N(N(v)) - N(N(u)) - Q_v \quad (4)$$

$$B_v = N(v) - N(u) \quad (5)$$

5: Node $v$ calls the selection process to determine $F(v)$ same as DP (i.e., Algorithm 1).

The correctness of excluding $N(N(f_{\text{i}}))$ from $N(N(v))$, where $F(u) = \{f_1, f_2.., f_m\}$ in case of $f_i \in (F(u) \cap N(v))$ and $ID(f_i) < ID(v)$, is shown in the following *Theorem 1*.

*Theorem 1:* If a node $x \in N(N(v))$ and also $x \in N(N(w))$, then x can be excluded from $U_{\text{v}}$. [Condition: $v$ and $w \in F(u)$, $w \in N(v)$ and $ID(w) < ID(v)$]

*Proof:* $U_{\text{v}}$ set contains the nodes which needs to be covered by $v$ and exactly 2-hop away from $v$. If a node $x$ is in $N(N(v))$ and $x$ is also in $N(N(w))$, then three cases may happen: (1) $x \in N(w)$, (2) $x \in N(v)$ and (3) $x$ is exactly 2-hop away from both $v$ and $w$ and not in $N(N(u))$, $x \in N(N(v)) - N(N(u))$ and $x \in N(N(w)) - N(N(u))$. For cases (1) and (2), $x$ can easily be excluded from $U_{\text{v}}$ as it will receive the packet when node $v$ and node $w$ will forward the packet. It is confirmed that, both node $v$ and $w$ will forward because they both are in the forward list of previous hop which is node $u$.For case (3), in case of TDP, the node $x$ will be covered by both $v$ and $w$. Thus, $v$ can exclude node $x$ from $U_{\text{v}}$ as $x$ will be covered by node $w$. [In case of $ID(w) < ID(v)$]

Now, the nodes selected from $B_{\text{v}}$ set can cover the nodes in $U_{\text{v}}$ is shown in *Theorem 2*:

*Theorem 2:* Let $U_v = N(N(v)) - N(N(u)) - Q_v$ and $B_v = N(v) - N(u)$ where $Q_v = Q_v \bigcup N(N(f_i))$, then $U_v \subseteq N(B)$.

*Proof:* In [12], authors have shown that, using the fact that $N(X) - N(Y) \subseteq N(X - Y)$, $N(B) = N(N(v) - N(u))$ can cover $U_v = N(N(v)) - N(N(u))$. Here, $Q_v = N(N(N(v) \cap N(u)))$,when ID of the nodes in $N(v) \cap N(u)$ are smaller than ID of node $v$. Therefore, it is clearly seen that, when $Q_{\text{v}}$ is subtracted from $U_v = N(N(v)) - N(N(u))$, $U_v(ExDP) \subseteq U_v(TDP)$. So, $N(B)$ can cover newly constructed $U_{\text{v}}$.

### B. Example

Let us provide an example to demonstrate the operation of DP, PDP, and TDP along with ExDP to show the differences. For this, a sample network shown in Fig. 3 is considered. The neighbor list of each node is illustrated in Table I.

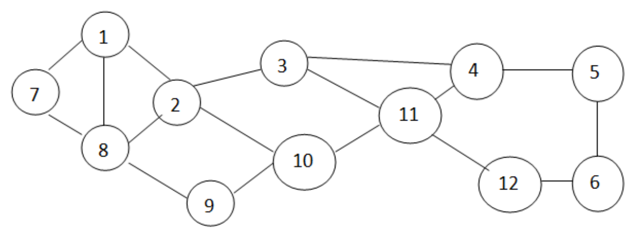



Fig. 3: A sample network of 12 nodes with source node 2 to show the improvements of the proposed method

Suppose, node 2 has initiated a broadcast. The detail construction of $U$, $B$ and $F$ set for DP is shown in Table II. It takes total 9 nodes to forward the packet to cover the whole network, including the original broadcast initiated by node 2.

For this network, PDP works in a similar manner, except some of the $U$ sets become smaller than DP. For this sample network, the result of PDP is shown in Table III. From Table III, we can see that when node 4 and 11 forwards, the size of $U_4$ and $U_7$ for PDP is smaller than the size of these $U$ sets in DP. The details of number of forwarding for TDP are given in the Table IV. Now, let us trace the behavior of the proposed Extended Neighbor Information based Dominant

TABLE I: 1-hop and 2-hop Neighbors of Each Node

| v | N(v) | N(N(v)) |
|---|---|---|
| 1 | 1,2,7,8 | 1,2,3,7,8,9,10 |
| 2 | 1,2,3,8,10 | 1,2,3,4,7,8,9,10,11 |
| 3 | 2,3,4,11 | 1,2,3,4,5,8,10,11,12 |
| 4 | 3,4,5,11 | 2,3,4,5,6,10,11,12 |
| 5 | 4,5,6 | 3,4,5,6,11,12 |
| 6 | 5,6,12 | 4,5,6,11,12 |
| 7 | 1,7,8 | 1,2,7,8,9 |
| 8 | 1,2,7,8,9 | 1,2,3,7,8,9,10 |
| 9 | 8,9,10 | 1,2,7,8,9,10,11 |
| 10 | 2,9,10,11 | 1,2,3,4,8,9,10,11,12 |
| 11 | 3,4,10,11,12 | 2,3,4,5,6,9,10,11,12 |
| 12 | 6,11,12 | 3,4,5,6,10,11,12 |

TABLE II: The DP Algorithm

| u | v | $U_v$ | $B_v$ | F(v) |
|---|---|---|---|---|
| ∅ | 2 | 4,7,9,11 | 1,3,8,10 | 3,8 |
| 2 | 3 | 5,12 | 4,11 | 4,11 |
| 2 | 8 | 3 | 7,9 | [ ] |
| 3 | 4 | 6,10,12 | 5 | 5 |
| 3 | 11 | 5,6,9 | 10,12 | 10,12 |
| 4 | 5 | 12 | 6 | 6 |
| 11 | 10 | 1,8 | 2,9 | 2 |
| 11 | 12 | 5 | 6 | 6 |
| 5 | 6 | 11 | 12 | 12 |

TABLE III: The PDP Algorithm

| u | v | P | U | B | F |
|---|---|---|---|---|---|
| ∅ | 2 | ∅ | 4,7,9,11 | 1,3,8,10 | 3,8 |
| 2 | 3 | ∅ | 5,12 | 4,11 | 4,11 |
| 2 | 8 | 2,7,8 | ∅ | 7,9 | [ ] |
| 3 | 4 | 3,4,10,12 | 6,10 | 5 | 5 |
| 3 | 11 | 3,5,11 | 6,9 | 10,12 | 10,12 |
| 4 | 5 | ∅ | 12 | 6 | 6 |
| 11 | 10 | ∅ | 1,8 | 2,9 | 2 |
| 11 | 12 | ∅ | 5 | 6 | 6 |
| 5 | 6 | ∅ | 11 | 12 | 12 |

TABLE IV: The TDP Algorithm

| u | v | $U_v$ | $B_v$ | F(v) |
|---|---|---|---|---|
| ∅ | 2 | 4,7,9,11 | 1,3,8,10 | 3,8 |
| 2 | 3 | 5,12 | 4,11 | 4,11 |
| 2 | 8 | ∅ | 7,9 | [ ] |
| 3 | 4 | 6 | 5 | 5 |
| 3 | 11 | 6,9 | 10,12 | 10,12 |
| 4 | 5 | ∅ | 6 | [ ] |
| 11 | 10 | 1,8 | 2,9 | 2 |
| 11 | 12 | ∅ | 6 | [ ] |

Pruning (ExDP) algorithm. The total list for the proposed method is illustrated in Table V.

From Table V, it is clearly visible that, $Q_3$ set is empty because the other node in the forward list of node 2 is node 8 and which is not a neighbor of node 3. Thus, the forward list, $F(3)$ remains same as DP. The difference is seen when node 11 re-broadcasts the packet receiving from node 3. Forward list of node 3 is, $F(3) = \{4, 11\}$. Now, when node 11 forwards,

TABLE V: The ExDP Algorithm

| u | v | $Q_v$ | $U_v$ | $B_v$ | F(v) |
|---|---|---|---|---|---|
| ∅ | 2 | ∅ | 4,7,9,11 | 1,3,8,10 | 3,8 |
| 2 | 3 | ∅ | 5,12 | 4,11 | 4,11 |
| 2 | 8 | ∅ | ∅ | 7,9 | [ ] |
| 3 | 4 | ∅ | 6 | 5 | 5 |
| 3 | 11 | 2,3,4,5,6,10,11,12 | 9 | 10,12 | 10 |
| 4 | 5 | ∅ | ∅ | 6 | [ ] |
| 11 | 10 | ∅ | 1,8 | 2,9 | 2 |

it knows it's neighbor 4 is also in the forward list of node 3 and $ID(4) < ID(11)$, so 2-hops away neighbors of node 4 is deducted from $U_{11}$ set. Thus, it determines $Q_{11} = N(N(4)) = \{2, 3, 4, 5, 6, 10, 11, 12\}$, $U_{11} = \{9\}$ and $B_{11} = \{10, 12\}$. $U_{11}$ set is reduced than DP, PDP and TDP. Thus node 11 asks only node 10 to forward to cover node 9 whereas in case of DP, PDP and TDP both nodes 10 and 12 were in the forward list of node 11. Thats why, node 12 never forwards in case of ExDP. Finally, it is clearly seen that total 7 broadcasts are required to convey the packet to all the nodes in the network using 3-hop neighbor connectivity information which is a visible improvement over DP, PDP and TDP.

## V. Experimental Results

To show how much improvement can be achieved some simulation experiments were carried out in random networks. The following metrics are used to evaluate the performance:

1) **Number of Transmissions Required:** Total number of transmissions required to reach the packet to all the nodes in the network.
2) **Saved Rebroadcast (SRB):** SRB is represented as $(r - t)/r$; here $r$ is the total number of nodes receiving the packet and $t$ is the total number of nodes transmitting the packet.
3) **Energy Consumption:** 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. In ExDP, total energy required for propagating hello packets upto 3-hops will be more than other three approaches. Suppose $n$ is the total number of nodes in the network. For a single round the total number of hello packet transmissions $T$ and the total number of hello packet receptions $R$ in ExDP can be stated as follows:

$$T = \sum_{u=1}^{n} \Big(1 + \big|N(u)\big| + \big|[N(N(u)) - N(u)]\big|\Big) \tag{6}$$

$$R = \sum_{u=1}^{n} \Big(\big|N(u)\big| + \big|N(N(u))\big| + \big|N(N(N(u)) - N(u))\big|\Big) \tag{7}$$

Total energy of a network is calculated as the summation of the total energy to transmit a packet in the network, $E_{\mathrm{T}}$ and the total energy for receiving the packet, $E_{\mathrm{R}}$. Total energy can be stated as:

$$E_{\mathrm{Total}} = E_T + E_R \tag{8}$$

TABLE VI: Parameters Used in Experiments

| Parameter | Value |
|---|---|
| Number of nodes | 100-500 |
| Area | 650m $\times 650m$ |
| Transmission range | 125m-225m |
| Transmission rate | 2Mbps |
| Broadcast data packet size | 1000 bytes |
| Hello packet size | 20 bytes |
| Transmission power of a node (1m) | -70 dBm (0.0000001mW) |
| Reception power | 80 mW |

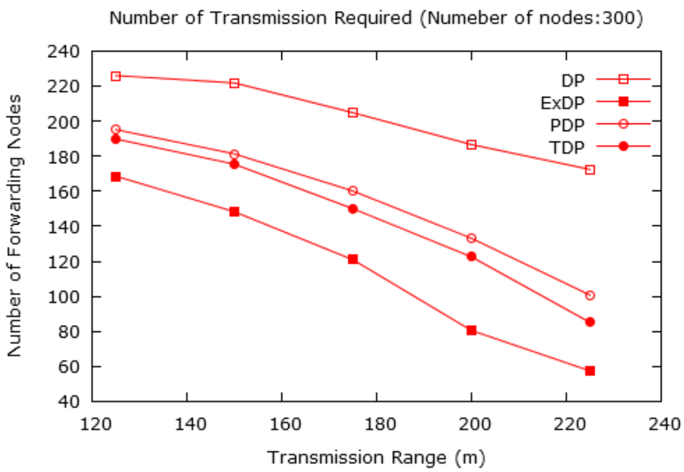



Fig. 4: Number of forwarding nodes of networks having 300 nodes by varying transmission range

Suppose, total $i$ nodes will forward among all the nodes in the network and the forward list is, $F = \{F_1, F_2, F_3, ...F_i\}$. 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, $E_T$ and $E_R$ of the network is defined as follows:

$$E_T = \left|F\right| \times P_t \times t \tag{9}$$

$$E_R = \sum_{F_i \in F} \left|N(F_i)\right| \times P_r \times t \tag{10}$$

The parameters and their values used in the experiment are summarized in Table VI. Total ten different scenarios were generated for each case and an average is taken. The simulation code was built using C++ programming language.

### A. Number of Transmissions Required

Figure 4 and 5 represents the effect of required transmissions by varying transmission range of network with 300 and 500 nodes respectively. It is obvious that the number of neighbors of a node already covered by other nodes increases with the increasing transmission range. ExDP excludes those covered nodes from the uncovered set and reduces re-transmissions. Figure 6 shows the required transmissions by adding nodes in a fixed transmission range (175m). As the number of nodes increases, the required transmission also increases and we can conclude ExDP performs much better than others.

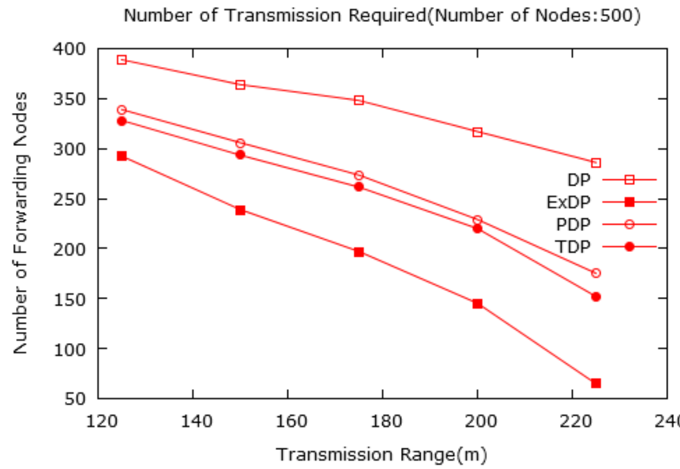



Fig. 5: Number of forwarding nodes of networks having 500 nodes by varying transmission range

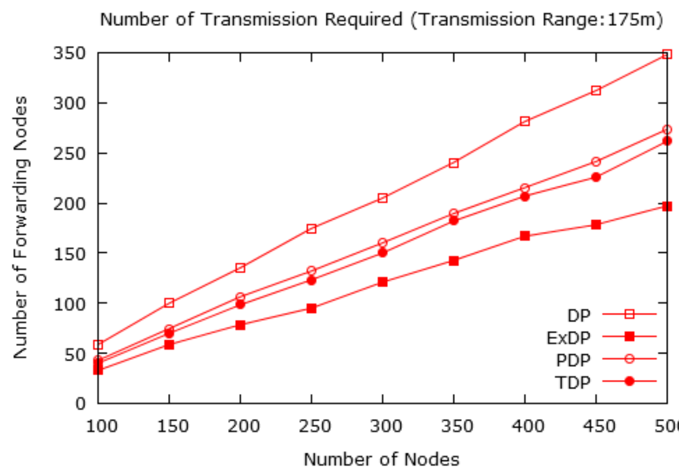



Fig. 6: Number of required transmissions by varying number of nodes in a transmission range of 175m

### B. Saved Rebroadcast (SRB)

Similarly in Figure 7, with the increasing number of transmission range the percentage of SRB increases. For the network with 300 nodes, ExDP proposed in this paper is able to save from 19% (125m) up to 39% (225m) than DP. Figure 8 shows, networks having 500 nodes also improve efficiency by saving rebroadcasts from 20% in case of lower transmission range to 44% in case of larger transmission range than DP. Here, only the number of nodes is greater than previous network, otherwise all the scenarios are same as before. This improved performance also remains if the number of nodes increases in a fixed transmission range which is clearly evident in Figure 9.

### C. Energy Consumption for Broadcasting Hello Packets

In Figure 10 energy consumption for a single round of hello packets is shown for a network having 300 nodes. As ExDP

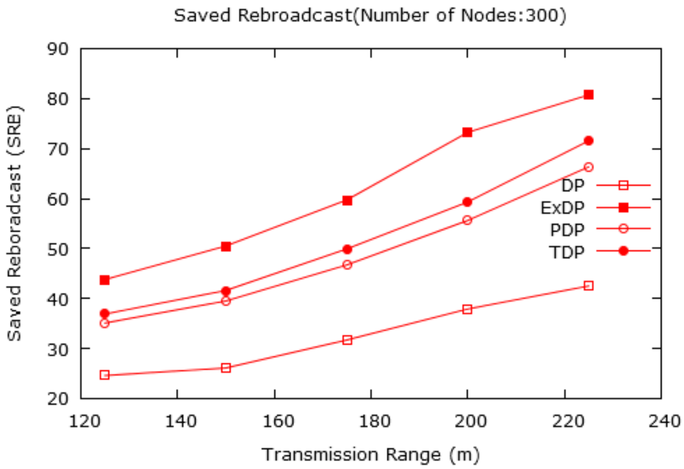



Fig. 7: Saved rebroadcast (SRB) of networks having 300 nodes by varying transmission range

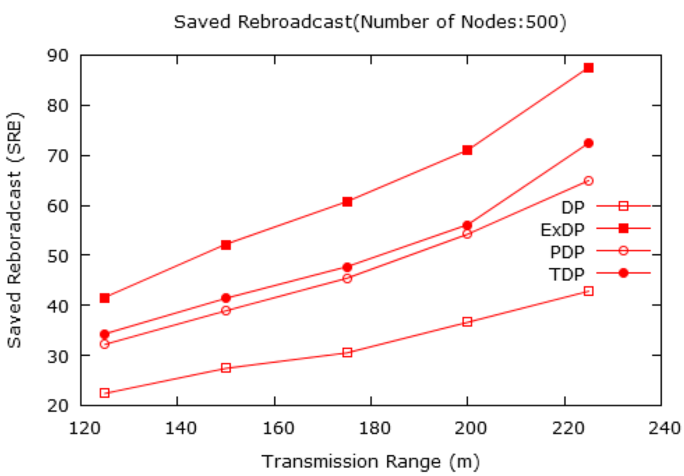



Fig. 8: Saved rebroadcast (SRB) of networks having 500 nodes by varying transmission range

require to propagate hello packets up to 3-hops instead of 2-hops the nodes consume more energy compared to the nodes in DP, PDP and TDP. From Figure 11, we can see the additional energy required for ExDP than DP for dense networks having 500 nodes. The same result remains if in a fixed transmission range more nodes are added. This is shown in Figure 12. Figure 10 and 12 show that ExDP always require more energy than DP, PDP and TDP while broadcasting hello packets as it requires to propagate hello packets upto 3-hops whereas others need to broadcast packet upto 2-hops.

### *D. Energy Consumption for Broadcasting Data Packets*

Figure 13 and 14 represents total amount of energy required to transmit a data packet to all the nodes in a network havig 300 nodes and 500 nodes respectively by varying transmission range. Figure 15 shows the performance of all four algorithms by keeping transmission range fixed but adding nodes to the

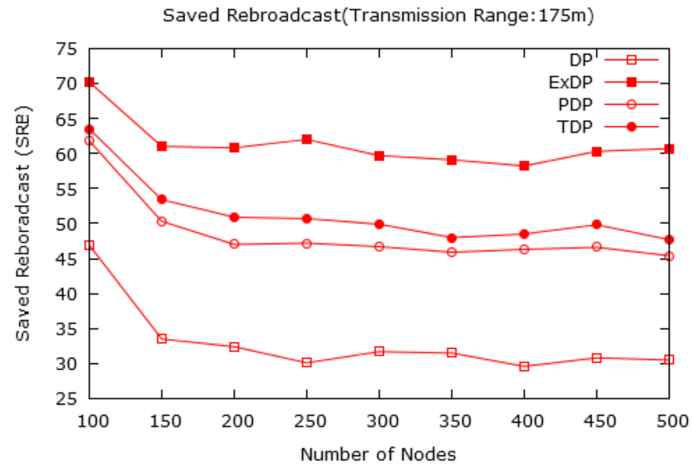



Fig. 9: Saved rebroadcast (SRB) by varying number of nodes in a transmission range of 175m

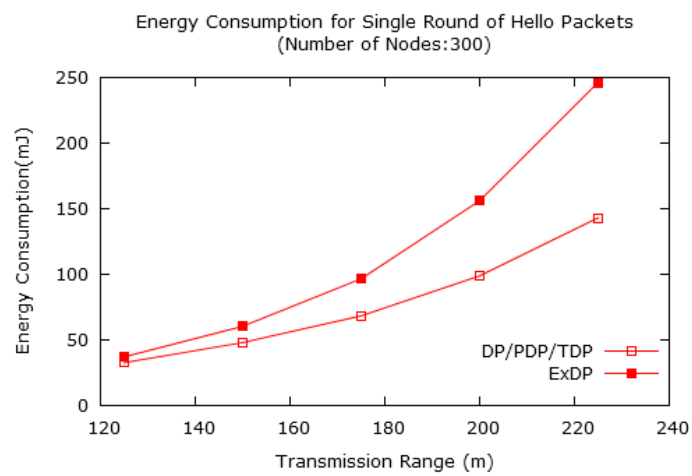



Fig. 10: Total energy consumption for a single round of hello packets of networks having 300 nodes (the transmission range is varied)

network. With the increasing value of transmission range total consumed energy by DP also increases. On the contrary, total energy consumed by ExDP decreases as the transmission range increases. ExDP reduced re-broadcasts than other methods. With the reduction in transmitting, also the total number of reception reduces. Thus, it is easily understandable that, ExDP will reduce energy consumption of the whole network to a great extent.

## VI. Conclusion and Future Work

In this paper, an efficient broadcast method for wireless ad hoc networks called *Expanded Neighbor Information based Dominant Pruning, ExDP* is proposed to mitigate broadcast storm problem by reducing rebroadcasting in a network. This method provides full network coverage as long as the network is connected. The new method, ExDP improves an existing

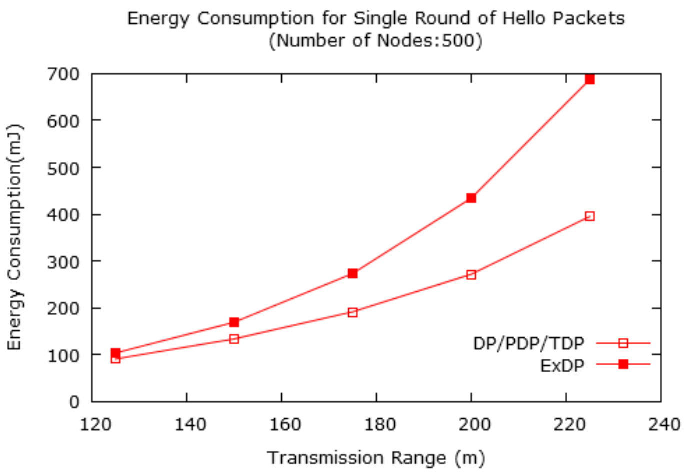



Fig. 11: Total energy consumption for a single round of hello packets of networks having 500 nodes (the transmission range is varied)

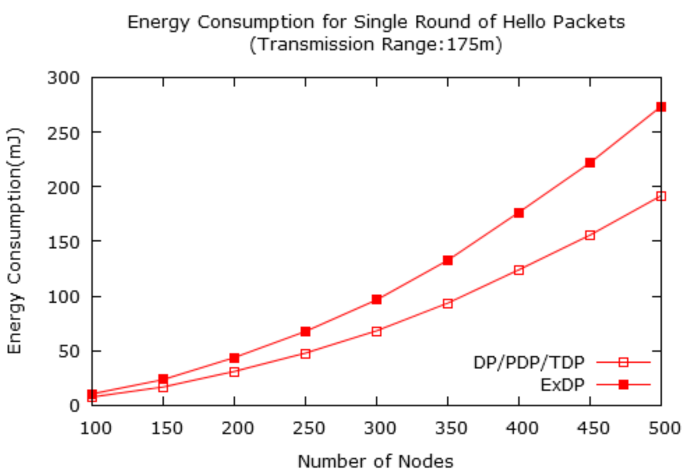



Fig. 12: Total energy consumption for a single round of hello packets (the number of nodes is varied)

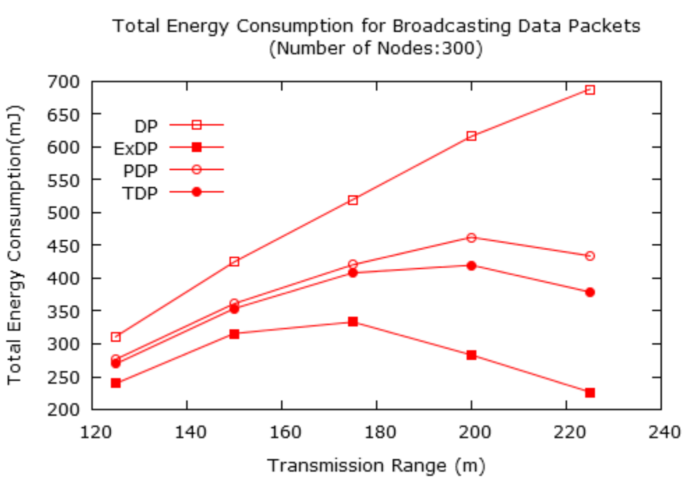



Fig. 13: Total energy consumption for broadcasting a data packet to the entire network of having 300 nodes ( the transmission range is varied)

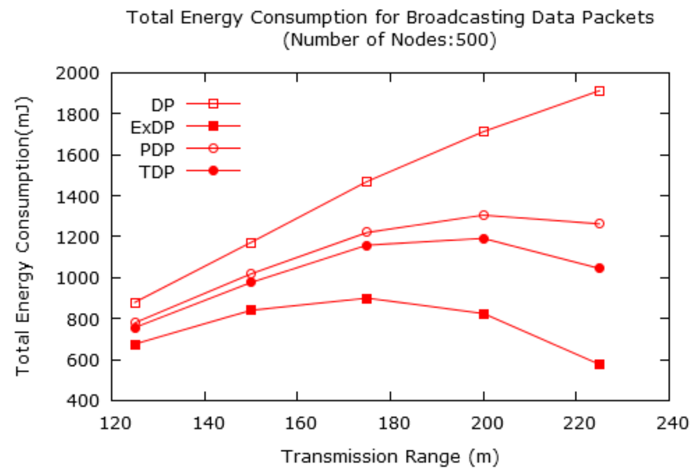



Fig. 14: Total energy consumption for broadcasting a data packet to the entire network of having 500 nodes (the transmission range is varied)

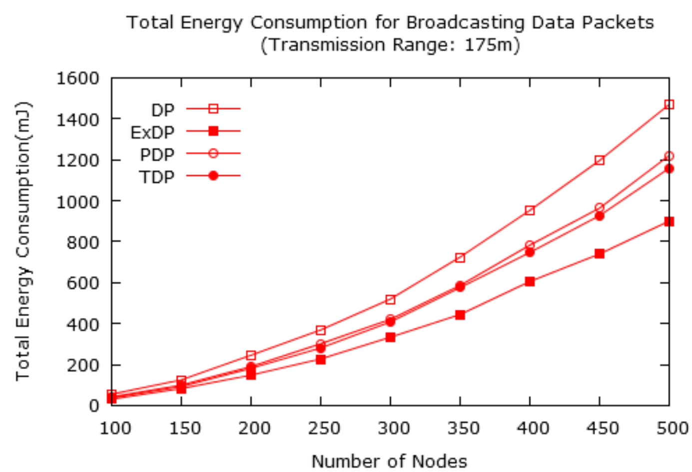



Fig. 15: Total energy consumption for broadcasting a data packet to the entire network (the number of nodes is varied)

broadcast technique, DP by expanding neighbor connectivity information of nodes in an ad hoc network. ExDP basically restores all the properties of DP except it uses 3-hop neighbor information of each node belongs to the network whereas DP uses 2-hop connectivity information. This paper work only considered static networks while conducting simulations. Future research can be conducted in mobile scenarios to see the effect of the proposed method in a high-mobility network. The 3-hop neighbor information may become stale in mobile scenario, a way can be suggested in future to handle the stale information.

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