Topological Broadcasting Using Parameter Sensitivity-Based Logical Proximity Graphs in Coordinated Ground-Flying Ad Hoc Networks

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Abstract

Ad hoc networks have been used in wide range of applications. These networks have become versatile as far implementation is concerned. Such networks have been used from static deployment to mobile network formations. Apart from Mobile Ad Hoc Networks (MANETs) and Vehicular Ad Hoc Networks (VANETs), another ad hoc formation with mobile nodes is the aerial ad hoc networks also termed as Flying Ad Hoc Networks (FANETs). A coordinated network formation between the ground ad hoc network and aerial ad hoc network provides vast applications in both civilian and military activities. Various existing issues of mobile networks can easily be resolved using aerial network formations. However, these networks similar to the traditional ad hoc formations are having a major issue of broadcast storming and network partitioning. These issues hinder the performance of such networks. Broadcast storming refers to replication of similar data in the network that increases the overheads which ultimately leads to network failure. In this paper, broadcast storming is considered as a problem and a possible solution is provided for it by keeping control over network partitioning issues. The proposed approach uses parameter sensitivity which is derived over optimized value of nodes configurations to form a topological arrangement. This topological arrangement is formed using logical proximity graphs which operate over link weight and parameter sensitivity. The proposed route discovery strategy under the proposed approach is capable of handling issues related to broadcast storms without affecting the network performance.

Keywords: FANETs, Broadcast storming, Parameter sensitivity, Routing, Topology.

1 Introduction

Multiple ad hoc networks operating in coordination with each other can provide vast range of applications. One of the important applications of such coordinated network is formation of ad hoc networks between the ground and the aerial nodes. This coordination can help attaining various complex tasks such as surveillance, ground monitoring, inter-terrestrial security, etc. Ground networks involved in such type of hybridization can be either mobile ad hoc networks (MANETs) or vehicular ad hoc networks (VANETs) [1]. The coordination between these two different ad hoc networks depends upon the efficient topological formation that allows fault-tolerant and continuous connectivity. An efficient topology would allow increased performance of the network in terms of data delivery, accuracy and enhanced life time of the network. Such coordination can either be provided using physical layouts or service coordination [2] [3]. Service coordination is virtual and is much affected by the physical connectivity of the

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nodes and the quality of link between them. Networks with nodes operating in different environments have greater risk of undergoing issues of network partitioning that can further lead to redundant data over the nodes after re-initiating the previously deactivated links. Such redundancy causes over-occupancy of the channels that leads to overheads. These overheads consumes much resources in processing already processed data floating in the network. This causes depletion of network resources which results in network failures. The issue of multiple copies of similar data gathering in the network is termed as broadcasting storm [4]. Broadcast storm is not a new issue. It existed from the starting of networks using omni-directional antennas that uses radio waves broadcasting for route discovery and data transmission [5]. With nodes being mobile, this issue becomes severe resulting in adverse affects such as network breakdown, node failures, session loss etc. [6]. Further, networks involving aerial nodes and ground nodes as part of common ad hoc units cannot be kept aloof from such issues. Therefore, efficient approach is required that can provide topological arrangement at the initial stage of network formation resulting in lower overheads and decreased redundancy in case of link failures.

In this paper, broadcast storm issue over the coordinated network formation between the ground ad hoc and the aerial ad hoc units is considered. A topological approach is proposed based on the parameter sensibility which helps in formation of logical proximity graphs. These proximity graphs are then used to identify the efficient links between the source and destination that can provide reliable communications without causing any redundancy during broadcasting. Further, a proximity-sensitivity routing (PSR) algorithm is proposed which operates over the network proximity to identify the active links between the nodes and also finds the efficient path between the source and the destination by controlling the number of connections over the intermediate relays.

Rest of the paper is structured as follows: Section 2 provides insight of related work and problem definition. Section 3 presents the detailed proposed work with proper illustrations. Section 4 evaluates the performance of the proposed approach and finally, section 5 concludes the paper with key highlights and future work.

2 Related Work

The broadcasting problem lead to redundancy in the packet transmissions among nodes in the wireless ad hoc network which may lead to replica of messages and packet collisions. To limit the broadcast problem in VANETs, a selective reliable broadcast protocol was proposed by Vegni *et al.* [7] to efficiently limit the number of copies of same packets transmitted in the network. This protocol is based on the cluster based approaches where it automatically detects the vehicular clusters of common interests and cluster head is selected as opportunistic vehicle. Opportunistic vehicle retransmits the packets to the next hop to decrease the forward vehicles number. It is very efficient to detect next hop forwarders in a faster way. Another probabilistic approach named GOSSIP1 was proposed by Haas *et al.* [8] where GOSSIP(p) indicates that p is the probability of forwarding the packet by the node and (1-p) is the probability of the node that it will not forward the packets. Further, GOSSIP(p,k) is proposed where the node will forward the packets with probability equal to 1 for first k hops ensuring the connectivity between source and the k^{th} hop. The major drawback of the scheme was to determine optimal forwarding probability. The authors determined the probability between 0.65 to 0.75 for nodes lesser than 1000. The AutoCast scheme was proposed by Wegener *et al.* [9] where adaptive probabilistic retransmission scheme was proposed and the nodes broadcast the messages after certain period. The retransmission probability is dependent on the number of neighbours of the selected node and the broadcast interval is dependent on the number of neighbours as well as number of broadcasts per second. Khelil *et al.* [10] proposed an adaptive broadcasting scheme named Hypergossiping for partitioned MANETs where the network partitioning is detected by the implementation of 'Last Broadcast Received' or LBR list at the respective nodes to detect the network partitioning. It is assumed that the two nodes within one partition will have the same LBR list and in the different partition will have the different LBR list. LBR is needed only when a new neighbour is detected and the node compares its own LBR with the received LBR to detect the partitions. Shen *et al.* [11] proposed a technique GOSSIP_DIR2 where directional antennas and euclidean distance are used as factors to forwarding probability for the sectors 1 to S_c where S_c is the number of sectors for the directional antenna. The estimation technique is used to calculate the forwarding probability. The NCPR protocol was proposed by Zhang *et al.* [12] where forwarding probability is calculated based on the self pruning mechanism where the adjustment of forwarding probability is done according to the number of neighbours which are uncovered. The forwarding probability is calculated based on the connectivity and the additional coverage matrix. The threshold based techniques have also been proposed to reduce the broadcast storm in Wireless ad hoc networks. One of such technique was proposed by Tseng *et al.* [5] where the authors propose the adaptive schemes to choose the threshold value dynamically based on the connectivity. Each node can select the threshold adaptively according to its number of neighbours thus, the proposed scheme can reduce the replica messages and have up to date information of neighbours. In order to reduce the broadcast storm in a 2-dimensional area, Tonguz *et al.* [4] proposed three protocols; weighed p-persistence, slotted 1-persistence and slotted p-persistence. The schemes proposed can also be used to guide the routes to the routing protocols with lesser number of hop counts. The results have shown that the the packet loss rate is decreased considerably by the proposed techniques and the end to end delay is also kept at the acceptable rate. Wisitpongphan *et al.* [6] also proposed the probabilistic and timer based approach to mitigate the broadcast storm problem in vehicular ad hoc networks using weighed p-persistence, slotted 1-persistence and slotted p-persistence. The proposed schemes depend on the GPS information for the location information to calculate the relative distance to the source node and the proposed approach is distributed in nature. Tonguz *et al.* [13] proposed a distributed protocol named DV-CAST to reduce the broadcast problem in VANETs relying on the local topology information for the mitigation of broadcasting storm. It can also handle the problem of disconnected network by incurring a small amount of overhead. Further, distributed broadcast protocol, BRACER was proposed for Cognitive Radio Ad-hoc networks by Song *et al.* [14] for avoiding the broadcast collisions. The original available channel set is downsized intelligently and broadcasting sequences as well as scheduling schemes are designed to successfully increase the accurate broadcast ratio and decrease the delay incurred in broadcasting. Wei *et al.* [15] proposed a broadcast protocol, AHBP for mobile ad hoc networks in which broadcast relay gateways are used for rebroadcasting the messages. The broadcast relay gateways constituted of the network's connected dominating set. The broadcast collision and congestion is also reduced to a greater level by reducing the redundancy in broadcasting. Touzene *et al.* [16] propounded EGBB, a broadcast protocol based on grid for mobile ad-hoc networks which depends on the 2-dimensional grid view of the geographical region of the network. It utilizes the gateway nodes for each grid cell to rebroadcast the message. It uses the neighbourhood information for the node in grid cell by utilizing only eight adjacent grid cells from the neighbouring grids which increases the reachability and reduces the hop count. Tseng *et al.* [17] proposed a technique for differentiating the rebroadcast timing and reducing the possibility of redundant broadcasts in mobile ad hoc networks. To solve the problem, many probabilistic, counter based, location based, cluster based and distance based schemes were proposed. Peng *et al.* [18] had given message redundancy protocol based on the statistical and local topology based information. The message redundancy is reduced considerably thus, improving the network bandwidth and energy utilization. A detailed comparison of some of the popular approaches that provide successful eradication of storming problem is presented in Table 1.

Table 1: Comparison of Existing Approaches For Solution To Broadcast Storms

Approach	**Author**	**Ideology**	**Parameters Improved**	**Applicability**
Distributed Broadcast Suppression	Tonguz *et al.* [4]	p-persistence, Slotted 1-persistence and Slotted p-persistence	Packet loss rate, End to end delay	Wireless Ad-hoc Networks
Adaptive Threshold Selection	Tseng *et al.* [5]	Adaptive Location-based Scheme, Adaptive Counter based Scheme	Reachability, No. of transmissions, Neighbourhood coverage	Mobile Ad-hoc Networks
Probabilistic and Timer based Approach	Wisitpongphan *et al.* [6]	p-persistence, Slotted 1-persistence and Slotted p-persistence	Message delay, Packet loss rate, Message reachability, Message overhead	Vehicular Ad-hoc Networks
Selective Reliable Broadcast protocol	Vegni *et al.*[7]	Cluster based approach to detect next hop forwarder	Detection of clusters, Detection of next hop forwarders, Throughput, Average Message Propagation	Vehicular Ad-hoc Networks
GOSSIP	Haas *et al.* [8]	Fixed Probabilistic Approach	Optimal forwarding probability	Mobile Ad-hoc Networks
AutoCast scheme	Wegener *et al.* [9]	Adaptive Probabilistic Approach	Retransmission probability, Adjusted broadcast interval, Reliability	Vehicular Ad-hoc Networks
Hypergossiping	Khelil *et al.* [10]	Adaptive Broadcasting Scheme	Intra-partition forwarding, Retransmissions	Mobile Ad-hoc Networks
GOSSIP_DIR2	Shen *et al.* [11]	Directional Antennas and Euclidean Distance	Forwarding probability	Mobile Ad-hoc Networks
NCPR	Zhang *et al.* [12]	Self-Pruning Mechanism	Forwarding delay, Rebroadcast delay, Connectivity	Mobile Ad-hoc Networks
DV-CAST	Tonguz *et al.* [13]	Distributed Broadcast Protocol	Reliability, Efficiency, Scalability	Vehicular Ad-hoc Networks
BRACER	Song *et al.* [14]	Distributed Broadcast Protocol	Successful broadcast ratio, Broadcast delay, Collision avoidance	Cognitive Radio Ad-hoc Networks
AHBP	Wei *et al.* [15]	Broadcast Relay Gateway	Broadcast redundancy, Broadcast collision, Congestion	Mobile Ad-hoc Networks
EGBB	Touzene *et al.* [16]	2-dimensional Grid Cell View	End to end Delay, Packet collision ratio, No. of saved rebroadcasts, Reachability, Hop count	Mobile Ad-hoc Networks
Broadcast Storm	Tseng *et al.* [17]	Probabilistic, Counter based, Location based, Cluster based and Distance based schemes	Redundant rebroadcasts, Reachability, Average latency	Mobile Ad-hoc Networks
Reduction of Broadcast Redundancy	Peng *et al.* [18]	Topology Information, Statistical Information	Redundant messages, Network Bandwidth, Energy, Reliability	Mobile Ad-hoc Networks
Discovery Phase of routing protocols	Reina *et al.* [19]	Jaccard Distance	Forwarding Delay, Retransmission delay	Mobile Ad-hoc Networks
Hybrid Flooding Scheme	Reina *et al.* [20]	Expansion Metric	Reachability, Forwarding probability	Mobile Ad-hoc Networks
CAREFOR	Mostafa *et al.* [21]	Irresponsible Forwarding	Collision probability	Vehicular Ad-hoc Networks
EAG	Huang *et al.* [22]	Residual Energy of Nodes	Forwarding probability, Reachability	Mobile Ad-hoc Networks
Distributed GOSSIP	Huang *et al.* [23]	Density based Scheme	Coverage level, Successful transmission ratio	Mobile Ad-hoc Networks

2.1 Problem Statement

Aerial ad hoc networks operating in coordination with the ground ad hoc networks have multiple line of contacts between the network nodes. This allows formation of multiple channels for transmission. Multiple connections although improves the network reliability and fault tolerance but causes an issue of replicated transmission and multiple overheads that finally occupies the whole channel. This replication of data and channels by multiple nodes is termed as broadcast storming. This causes a serious drop in congestion window size which ultimately makes it difficult to continue transmission. The lowering of congestion window no doubt maintains connectivity, but this adds to a limitation of decreased performance. Therefore, an efficient approach is required that can focus not only on continuous connectivity but also lowers the issue of broadcast storming.

2.2 Our Contribution

Aerial nodes operating in continuous connection with the ground nodes have an added advantage of complete availability of line of sight in most of the cases. This line of sight provides strong connectivity between the ground and the aerial nodes. However, there is a disadvantage that same nodes can have line of sight availability to multiple aerial nodes. Thus, if a routing table is constructed for data transmission, and upon broadcasting of packets, it is liable that data gets travelled to same nodes in replication following multiple paths. A suitable approach is required that can keep check on this broadcasting and can ensure that data is not replicated as this will prevent overconsumption of network resources and will ultimately increase the network lifetime and performance. Thus, an efficient approach is required to form a topological arrangement of nodes in both the networks such that lower overheads due to data replication, least buffer overflows and continuous streaming are obtained between these coordinated networks. Using this ideology, parameter sensitivity based logical proximity graphs are used to form an efficient topological arrangement that eradicates the occupance of redundancy over the whole network. The key issues resolved by the proposed work are:

- Solution to broadcast storm in coordinated ad hoc network formed between aerial and ground nodes.
- Check on network partitioning.
- Continuous connectivity with improved fault tolerance of the network.

3 Proposed Work

A network formulated using existing topological arrangement between the nodes of two different ad hoc units lead to problem of broadcast storming. One of the reason of such problem in these networks is the availability of multiple data channels that can be used for reliable transmission. The problem deals with the prevention of replicated data in the whole network by controlling the topological arrangements of these networks and limiting the incoming/outgoing connections from a node. Broadcast storming mostly occurs during rehabilitation phase of a network. A broken link on reactivation attains same data which is already passed on the the connected node which causes multiple copies of same data. This data is again processed and causes wastage of network resources and also occupies the node by preventing them from receiving another incoming requests. A sample diagram illustrating the problem of broadcast storm is shown in Figure 1.

The proposed approach integrates the proximity graphs with the broadcasting principle of the existing ad hoc networks. These graphs are formed using concept of parameter sensitivity that helps in lowering

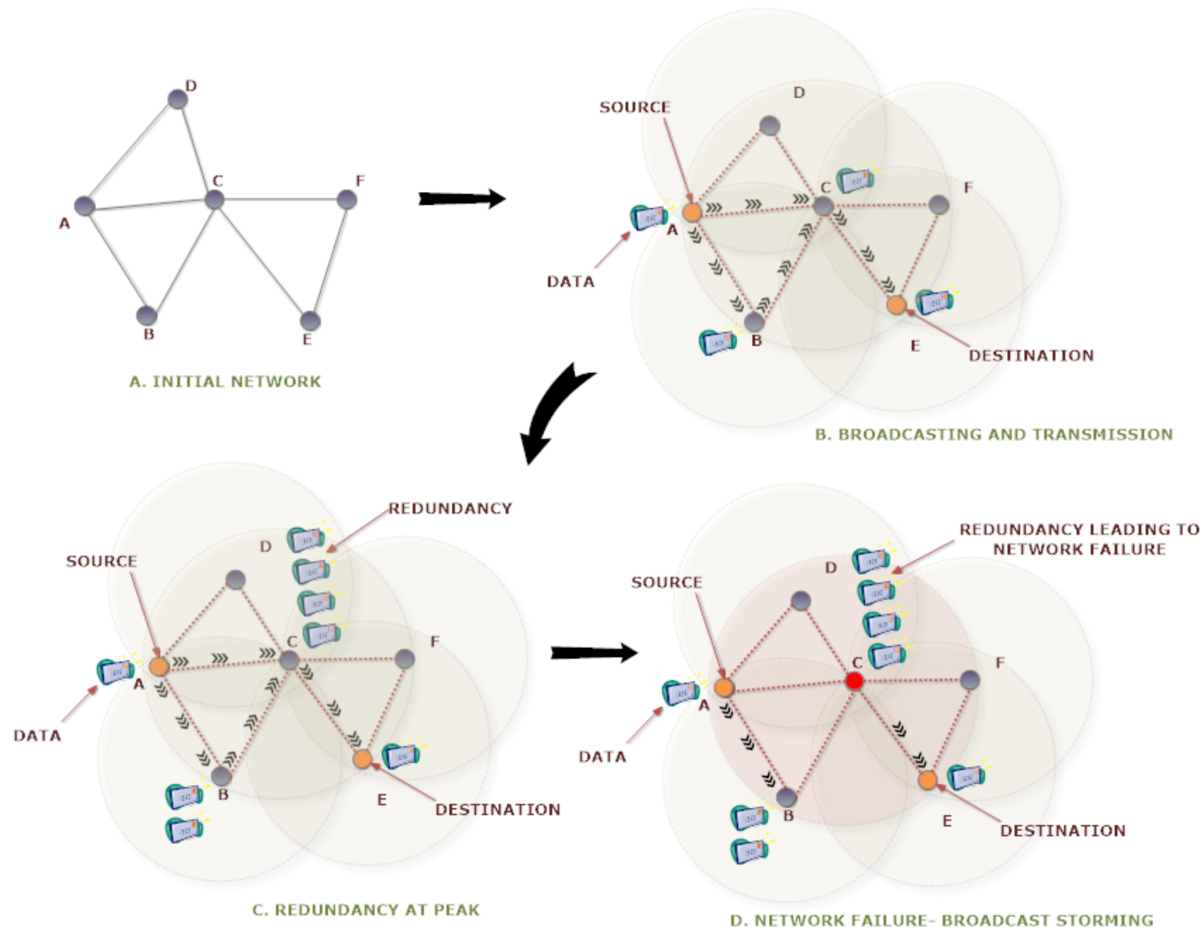

Figure 1: Problem Definition: Broadcast Storm

the overloaded connections. Traditionally, proximity is defined over some geometrical constraints while forming graphs. But, in this approach logical proximity is considered while forming connections between the nodes. The whole model operates in three parts.

- Derivation of parameter sensitivity for the network.
- Formation of logical proximity graphs using the parameter sensitivity.
- Integration to form the initial route finding algorithm between the source and the destination.

3.1 Network Parameter Sensitivity

Sensitivity in this paper is considered as the crispness in the value which will provide the optimized results for the whole network. Parameter sensitivity refers to the selection of best possible parameters for the identification of optimized link between the source and destination. Two types of parameter sensitivity are observed in the coordinating network formed between the aerial and the ground nodes. One is termed as the intra-parameter sensitivity which is observed between the nodes of the same network, and the another is the inter-parameter sensitivity which is observed between the nodes of two different networks. Formulation for parameter sensitivity is similar for both the types of network formations. Primarily, in this paper, inter-sensitivity is considered as this type of formation is new in ad hoc family and also, it requires crisp resolution to such problems. Parameter sensitivity aims at providing efficient network formation with continuous connectivity between the network nodes based on the optimally selected network nodes. In a network comprising of hybrid nodes, let $P_S^{i,j}$ be the parameter sensitivity between the nodes i and j. For connectivity between the nodes, $P_S^{i,j}$ should be maximum. This parameter sensitivity, $P_S^{i,j}$ operates on the set $S = \{x : x \in networkconfiguration and properties\}$ of network parameter that are to be maximized for continuous transmission. Note, that for each element in the set S, each element should attain its maxima when network operates at its full capacity i.e.

$$\lim_{t \longrightarrow t'} x^i \longrightarrow max \ ,\forall\, x \in S \tag{1}$$

where t' refers to time stamp where the network state acquires maximum transmission. This implies that when the network operates on full capacity, the dependent parameters also attain maxima. For a network with variable parameters, $P_S^{i,j}$ is defined as:

$$P_S^{i,j} \longrightarrow f(i,j,S) \tag{2}$$

where $f(i,j,S)$ is the connectivity function derived on source i, destination j, and the set of network parameters considered for optimization. Set S used in the parameter sensitivity comprises of following elements.

$$S = \{D^{i,j}, L_A^{i,j}, L_S^{i,j}, L_R^{i,j}\} \tag{3}$$

where $D^{i,j}$ is the geometrical distance, $L_A^{i,j}$ is the link availability, $L_S^{i,j}$ is the attained link speed, and $L_R^{i,j}$ is the approximated link reliability between the nodes i and j. Distance D is further dependent upon two variables: LoS which is boolean for availability of line of sight. False value makes D=0. For true boolean value of LoS, D is computed over R_B which defines the geometrical radio range between the nodes. R_B is computed as:

$$R_B = \frac{c}{\sqrt{RSS}} \tag{4}$$

where c defines the signal intercepts defined over noise. Its value can also be computed from shannon's noise capacity or can be directly replaced by the network pathloss. RSS is the received signal strength which is computed using existing formula [24]:

$$RSS = R_{min}^P - A_p \ \ \eta log_{10}(\frac{D_{max}}{B_r}) \tag{5}$$

where R_{min}^P is the minimum power rating attained by the network, A_p is the average pathloss, η is the actual pathloss, D_{max} is the maximum range of the radio signals, and B_r is the broadcast radius of the node. Link availability L_A is the maximum capacity a channel can offer and is derived over corridors available and probability of packets lost and received during initial handshakes. L_R is computed over successful delivery of packets as:

$$L_R = \frac{PDR \times C_{min}}{C_{max}} \tag{6}$$

where PDR is the packet delivery ratio over the link, C_{min} is the number of requests handled, and C_{max} is the maximum requests a channel can handle. Now, network parameter sensitivity P_S which operates over maximum optimized values of all the parameters on which the performance of the network depends, will be given as:

$$P_S = \frac{R_B}{\beta}\left[\Theta_1 \frac{L_S}{L_A} + \Theta_2 \frac{1}{D}\right] \tag{7}$$

Here, Θ_1 and Θ_2 are the transmission constants where Θ_1 operates over link metrics and Θ_2 operates over the physical constraints such that $0 \leq \Theta_1 \leq 1$ and $\Theta_1 \leq \Theta_2 \leq 1$.

For every communicating unit or connection, parameter sensitivity needs to attain the maxima throughout the connectivity. In the next step, this parameter sensitivity is used to form the logical proximity graphs that forms the basis for the topological arrangement which eradicates the issue of broadcast storm in such networks.

3.2 Formation of Logical Proximity Graphs

Proximity is derived over geometrical constraints in normal graphs. However, in the proposed approach logical proximity is considered which is derived over the parameter sensitivity of the various network parameters over which the network depends. Logical proximity refers to the identification of best/optimized link between the network nodes. For a regular routing, any of the existing algorithm can be used to fined the optimized path between the two nodes. Such graphs are formed on the basis of the acknowledgements and the handshakes. HELLO packets are broadcasted and are then used to find the path between the source and destination either using reactive or proactive approach. But such routing guarantees current state connectivity. All the packets are broadcasted by the omni-directional antennas. Nodes in connection with each other continues to receive data till the existence of the link. An alternate path is selected for transmission in case of link failures. No account of previously attained data is maintained in that cases which leads to problem of redundancy in such networks which increases the overall overheads.

An alternative approach is required that not only discovers the route but also, optimizes the connectivity by eradicating any redundancy in data over the same node. In a mobile network, redundancy is bound to happen. Also, another issue of network partitioning might arise due to node failure. Keeping these issues in view, parameter sensitivity is used to derive the logical proximity graphs which eliminates the effect of multiple connections with similar data as well as provides a possible remedy for network partitioning.

Let $G = (V,E)$ be the graph with V number of vertices and E number of edges corresponding to the route such that E accounts for all the edges between the source and destination. Graph G is optimized by P_S defined over each link such that new graph G_P is formed as logical proximity over G. Logical proximity graphs are different than the traditional proximity graphs. Rather than using geometrical considerations for the link between the nodes, logical proximity graphs use parameter sensitivity value and weight over the link between the nodes. For the graph $G_P = (V_P, E_P)$, $V_P \in V$ and $E_P \in E$. Also, $G_P \subset G$. This means that the final proximity graph will contain only those edges that satisfies the sensitivity over the particular edge between the two nodes. As a functional dependency, proximity graph can be defined as: $G_P = P(G)$ where P denotes the graph function operating over V and E. In the initial phase, existing network is used and HELLO based parameter values are obtained by the sender using acknowledgements. Proximity is computed over each link of pre-existing graph such that:

$$P_R = W \times P_S \tag{8}$$

where W defines the link weight between the two nodes and is computed as:

$$W = \frac{C_H^M}{I} \tag{9}$$

where C_H^M is the maximum number of channels available. I defines the interconnections currently active on the node. It can be noted that in a regular graph, more number of interconnections is preferred. But, in the proposed approach only required number of interconnections are used in order to eradicate the replicated connections. Also, for a non-receival of acknowledgments or negative acknowledgments, $W = 0$. Also, for a radio range $r >> Th_r$, $P_S = 0$ where Th_r is the threshold upto which the connection holds. Now, based on the threshold proximity P_R^{TH} which is attained over the average expected value of sensitivity of each parameter, form a sub graph with new vertices and new edges. These edges are determined as proximity links L_P between the two potential network nodes P_P. Thus, by definition, G_P can also be defined as:

$$G_P = (P_P, L_P) \tag{10}$$

Higher the value of L_P, better is the quality of the link. In a network, all the edges that obeys the threshold value of proximity, are treated as active links, thus, for a fully connected graph G with all links in active state, $G_P \subseteq G \ \forall \ L_p \in E$. If in a network, single proximity link is available between the nodes, then the graph is directly used for route formation and data is transferred. But, this happens only in best cases. In the rest of the scenarios, is likely that nodes have multiple proximity links and some of the nodes might be isolated leading to network partitioning. In that case, the proximity-sensitivity routing (PSR) algorithm is used to identify the next nodes and the actual governing links. This PSR algorithm identifies the multiple proximity links and selects one possibility by overcoming the network partitioning problem (if any) in the final proximity graph.

3.2.1 Proximity-Sensitivity Routing (PSR)

Selection of optimal links after formation of final proximity graphs is not as simple as picking the best value. This may lead to full network failure or multiple partitioning which makes the network nodes unreachable. This selection is however, based on the proper rules and sustaining rate of each of the link available as path between the network nodes. In such cases, node heading and direction are also taken into consideration. PSR does not provide a full routing between the source and destination, rather it only provides selection of possible optimized routes between the nodes without isolating any node. Various steps involved in PSR are as follows:

1. Compute initial proximity which is always defined for the incoming requests. Now as the wireless ad hoc networks operate over bi-directional links, count of degree is traced for each of the node.
2. Now, pre-analyze the whole network based on the P_R^{TH}. Virtually eradicate single link from each node and check if a node gets isolated or not.
3. If a node gets isolated, hold the link, mark it as conquered and give a counter to it. Otherwise, prompt for neighbouring nodes of source in the next HELLO message.
4. Eliminate a receiver's connection from the nodes that are directly related to the source. Again check for isolation and proceed further.
5. Now perform the similar operation towards the other nodes that act as relay and forms a direct connection with the destination. Steps 4 and 5 will provide with active proximity links that are directly connected to the source and destination.
6. Repeat the whole process considering another nodes as source and destination till all the cycles in the network graph are removed and each node possesses a single path towards the other node.
7. In case of similar indexing with the links, apart from the source and destination, hold the link with greater proximity value.
8. Finalize the graph. It can be traced that a proximity based optimized route is available between the network nodes that will decrease any chances of redundancy and thus, will lower the network overheads. This whole process of implementation of PSR is illustrated in Figure 2.

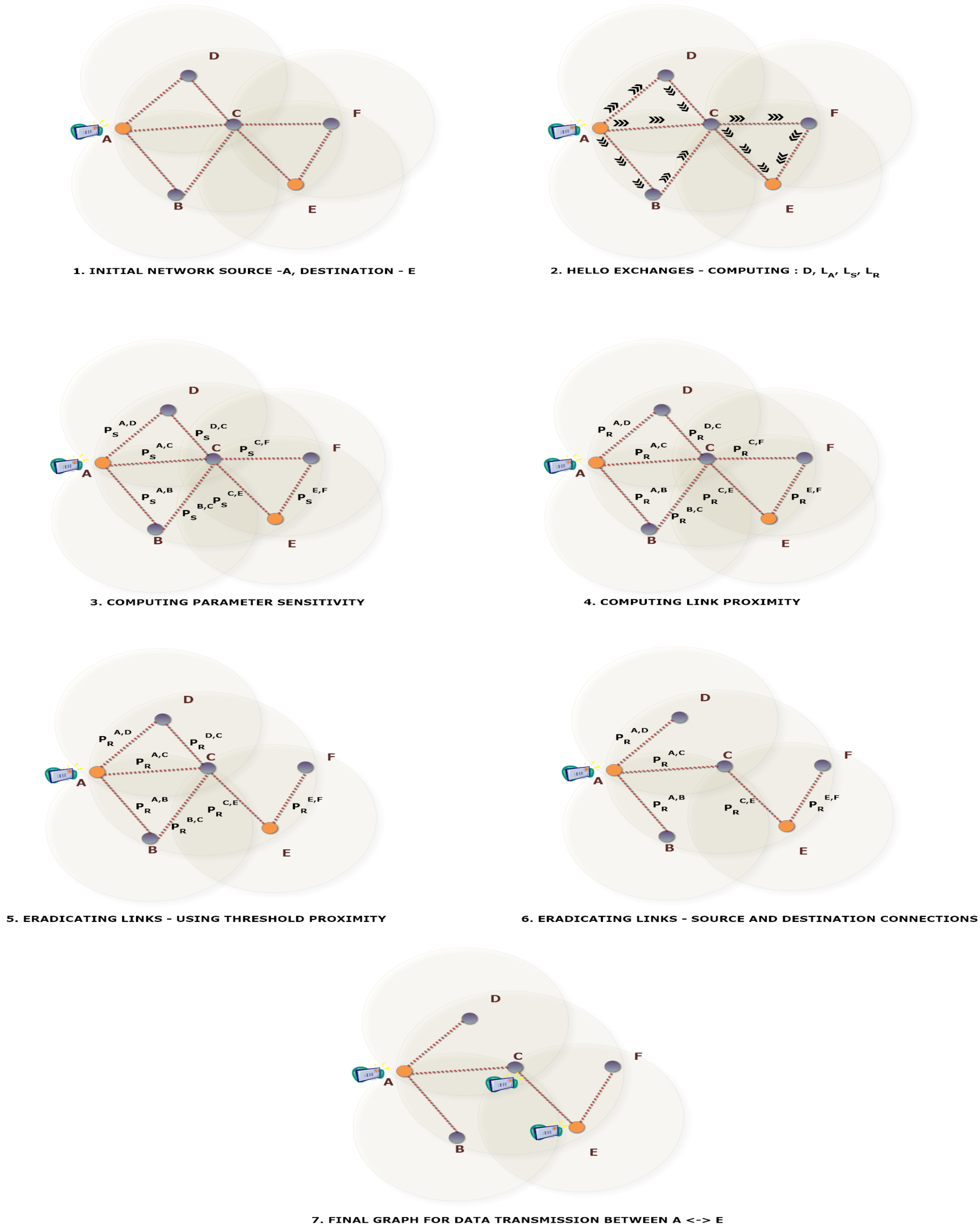

Figure 2: Proximity-Sensitivity Approach - Proximity Graph Formation

3.2.2 Managing Network Partitioning and Congestion Window

In a network comprising of two variedly operating ad hoc units, chances of network partitioning are more as compared to traditional ad hoc networks. Nodes that do not obey the policies of the logical proximity graphs may get isolated thus leading to network partitioning. Two approaches are used to recover such nodes. One of the approach is re-broadcasting to allow re-configuration of nodes that will adjust the weight of the link which will make its connection active. Other is limiting the increase of congestion window to conquer the link between the isolated node and other network nodes. Congestion window is increased on the basis of standard tcp-protocol used in the initial configurations of the network. However, in order to overcome the isolated nodes, congestion window size *cwnd* is decreased as:

$$cwnd = cwnd - \frac{RTT}{P_S}, \ such \ that \ P_S \geq P_S^{TH} \tag{11}$$

This would re-activate the links and no nodes will remain isolated. However, this solution can lead to over consumption of network resources due to multiple retransmissions. This may lead to node failure due to faster utilization of resources than the normal state which may cause the network to sigh off. These issues can be targeted as futuristic research issues to provide a more optimal solution in the proposed PSR algorithm. Algorithm 1 presents the steps used in eliminating the links that causes redundancy in the network.

Algorithm 1 Proximity Sensitivity Based Route Selection

Require: $source, destination, G = (V, E)$
Ensure: $radio\_range = set, links = active$

```
Initialize G = (V,E)
Establish link(G)
interconnections_counter=link_count(G)
multiple_interconnections =true, i=1
while (multiple_interconnections !=false) do
    broadcast ⟶ "HELLO" messages
    S ⟵{D^{i,j}, L_A^{i,j}, L_S^{i,j}, L_R^{i,j}}
    Compute ⟵ P_S
    Assign ⟵W
    j=1
    while (j ≤ V) do
        Compute ⟵ P_R
        if (P_R ≥ P_R^{TH}) then
            Save ⟵ link (Source,j)
            if (interconnections(j)> 1) then
                Remove ⟵duplicate_links(Source,j)
            else
                continue
            end if
        else
            Check partitioning
            if (partitioning=true) then
                re-initialize ⟵configurations(j)
                decrement ⟵ cwnd
                Adjust ⟵ W
            else
                continue
            end if
        end if
        j=j+1
    end while
    decrement ⟵ interconnections_counter
    i=i+1
end while
```

$Source$	$Next\_hop$	P_S	W	P_R	$Previous\ P_R$	P_R^{TH}

Table 2: PSR: Memory Table

3.3 Data Structures

A link layer based data structure was used to realize the formation of the proposed approach. These data structures were used to store and process the routing data which is used in formation of final route between the source and destination. Two tables are used in the proposed approach. All the entries of these tables utilizes the concept of underlying link list formation as this allows dynamically configurations of the network at any time. Also, threading is easily attained in such data structures. Initially a memory table (shown in Table 2) is used to store the initial configurations of the links during the first broadcasts. It is then replaced by the entries based on the time stamps. Broadcast entries such as next hop, its id, proximity values, weight, previous value for proximity, threshold defined are all stored in this table. Further, this table is used to decide the final route between the source and destination by forming the broadcast routing table as shown in Table 3. This table is used to select the final path between the nodes. The table is updated whenever there is change in network configurations or when the node gets out of the radio range of the sender node. This table also maintains a check on congestion window which is used to bring-up any isolated node in the network.

$Next\_hop$	$Hop\_location$	P_S	W	$LastUp$	P_R	RTT	$cwnd$

Table 3: PSR: Broadcast Table

4 Performance Evaluation

The proposed PSR algorithm provides a possible remedy against the network redundancy that may lead to multiple failures and network partitioning. The proposed algorithm utilizes a new concept of parameter sensitivity to derive the logical proximity graphs that directly gives the efficient route between the source and destination with minimum number of sub-interconnections that are the major causes of network redundancy. The proposed approach was analyzed using network simulations configured over $NS-2$ and $Matlab^{TM}$. Matlab was used to attain the behaviour environment for UAVs and NS-2 was used to provide ground scenario for coordinated network formation. Traffic for network was generated using standard NS-2 model. Same procedure was used to generate traffic for the aerial networks. The coordination between these networks was controlled using existing cooperative framework [1]. Number of ground nodes varied from 10 to 100 and number of aerial nodes were kept between 5 to 20. Standard IEEE 802.11 band was used for ground communication. Simulations configured the nodes with antennas capable of handling UHF/KU band for ground-aerial coordination. Mobility of ground nodes was varied between 5 m/s to 20 m/s to analyze the effect of movement over broadcasting. Random waypoint topology model was used for ground nodes. Aerial nodes were configured pre-hand and were given fixed waypoints over an area of 2500x2500 m.sq. The initial threshold for the proximity was set at the average value of the overall proximity attained during initial handshakes. Various other parameters configured for performance analysis of the proposed approach are given in Table 4. Number of interconnections

PARAMETER	VALUE
Dimensions	2500x2500 sq. m
Ground Nodes	10-100
Aerial Nodes	5-20
Traffic Type	CBR
Packet Size	1024 bytes
Antenna Type	Omni-Directional
Transmission Mode	Broadcast
Maximum Buffer Size	20000 bytes
Propagation Model	Two Ray Ground
Aerial Speed	15-20 m/s
Ground Speed	5-20 m/s
Pause Time	20s-40s
Aerial Transmission Range	1.3km
Initial Bandwidth	54 Mbps
Simulation Runs	100

Table 4: Network Configurations for Performance Analysis

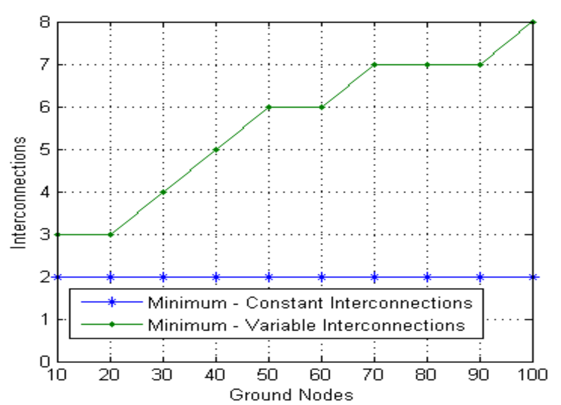

Figure 3: Interconnections: Constant and Variation

available over the considered network is shown in Figure 3.

During initial analysis, the network was tested for its configurational performance. A network with better connectivity is able to sustain high rate for link reliability. However, with increase in number of nodes, broadcasting will lower the transmission speed which in reverse affects the network reliability. Network with more number of aerial nodes provide better line of sight, thus, reliability is higher in them. Link reliability was tested against number of ground nodes operating under constant and variable interconnections with each other. The graph for link reliability using 5 and 20 UAVs is shown in Figure 4 and Figure 5, respectively. During initial network formation, the network heavily broadcasts the packets to form the route between the source and the destination. With more number of interconnections on each node, link speed gets restricted under a certain limit, thus affecting the transmission between the source and destination. The variation of link speed with number of UAVs over ground nodes with variation in type of interconnections is shown in Figure 6 and Figure 7. As explained in the proposed section, the proximity sensitivity routing operated over parameter sensitivity value is derived over each link of

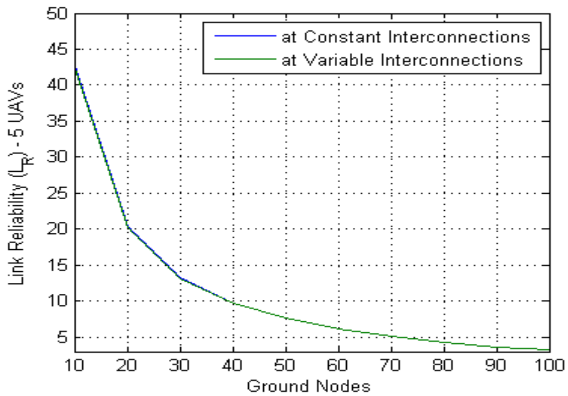

Figure 4: Link Reliability Using 5 UAVs

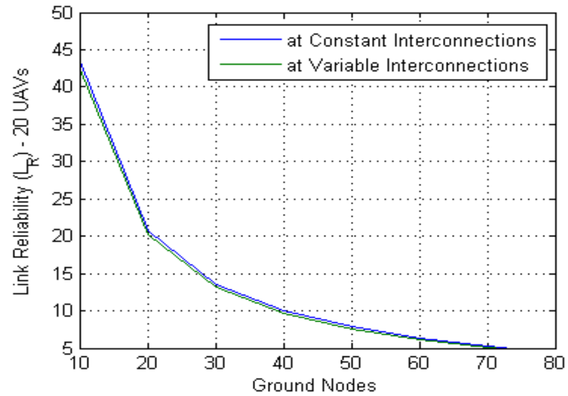

Figure 5: Link Reliability Using 20 UAVs

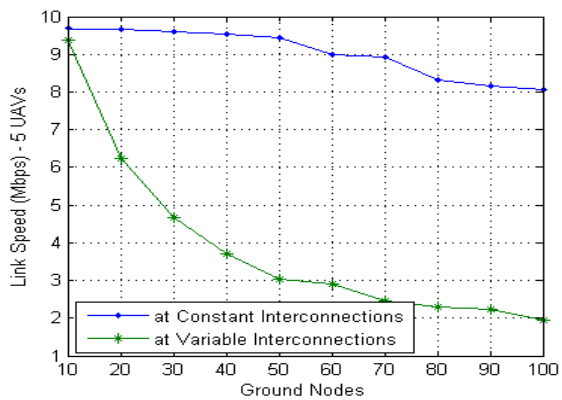

Figure 6: Link speed Using 5 UAVs

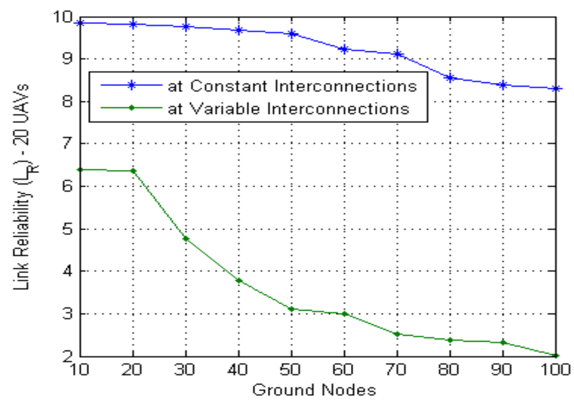

Figure 7: Link Speed Using 20 UAVs

the final connected graph. Values were traced for network link sensitivity values and a comparative plot was formed for average parameter sensitivity value for complete network as shown in Figure 8 and Figure 9. Further, this parameter sensitivity values are used to derive the actual proximity of the network. This proximity is used to select if the actual network will operate under the configured conditions. This logical proximity will determine the state of the link and will also affect its selection for final graph. A graph with maximum proximity value is more stable than the lower one. The comparative plot for network logical proximity using variation in number of UAVs is shown in Figure 10 and Figure 11.

After initial analysis of the network, the whole system was deployed for its comparison with the existing selective flooding and regular broadcasting approach. Selective flooding refers to data broadcasting when required based on the link selection. Selective flooding is a self generated scenario created using traditional flooding [14]. Regular broadcast is the normal approach of HELLO exchanges which are performed whenever a node searches for path or when a link breaks. 20 UAVs were maneuvered over the ground nodes ranging from 10 to 100. Traces were generated to analyze the network performance based on the broadcasting and redundancies. Lower requirement of broadcasting refers to efficient network formation. Proposed PSR algorithm required 53.67% less broadcasts than the selective flooding approach and 56.29% less broadcasts than the regular broadcasting approach. The plot for broadcast comparisons

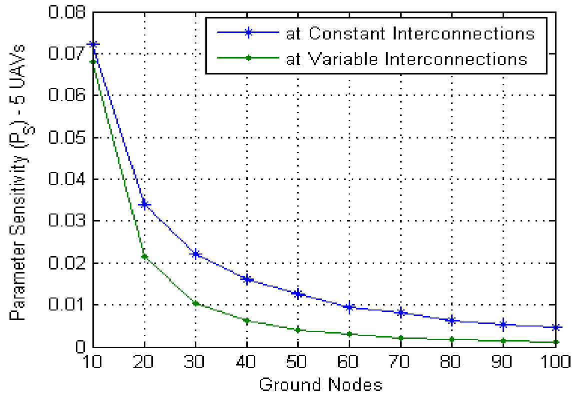

Figure 8: Parameter Sensitivity Using 5 UAVs

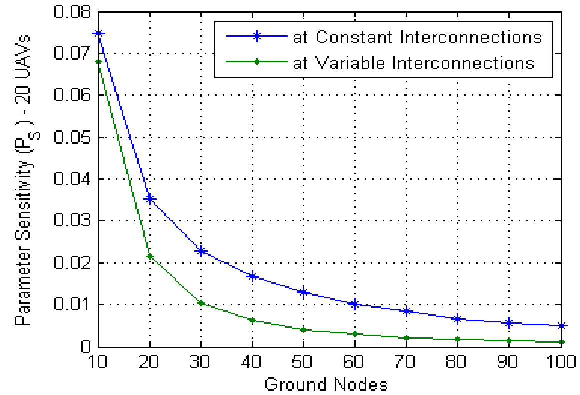

Figure 9: Parameter Sensitivity Using 20 UAVs

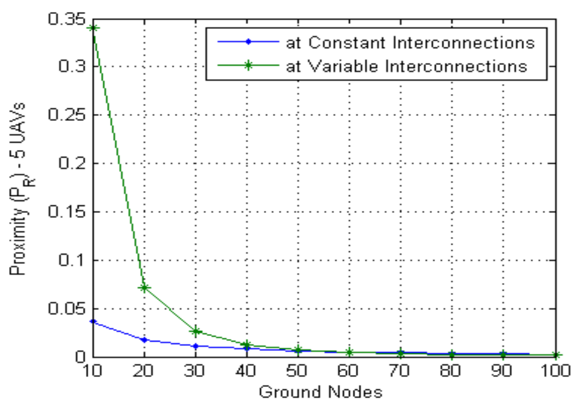

Figure 10: Logical Proximity Using 5 UAVs

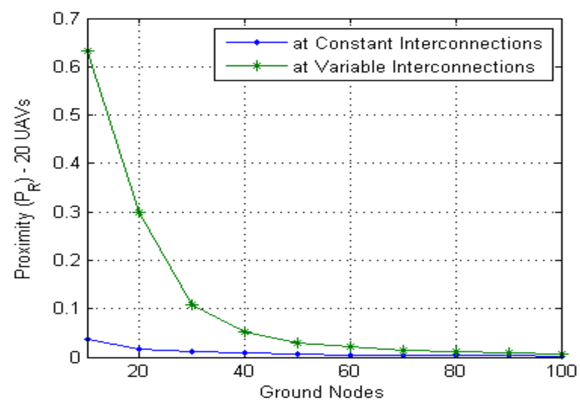

Figure 11: Logical Proximity Using 20 UAVs

is shown in Figure 12. Network was then analyzed for packet delivery ratio. Higher value of delivery ratio denotes efficient network formation. PSR provided 7.5% more delivery than the selective flooding approach and 10.72% more than the regular broadcasting approach as shown in Figure 13. Link failures hinders the performance of the network. A network with failed links has to recover the faulty links. This recovery time directly affects the overall transmission and also adds upto the total broadcast overheads. These overheads should be least and well controlled as their value beyond a certain limit can stop the overall functioning of the network. The proposed PSR took 51.98% less time in recovering from faulty links in comparison with selective flooding and 66.03% less time in comparison with regular broadcasting approach. The comparative plot for link recovery time in contrast with variation in number of nodes is shown in Figure 14. Also, PSR caused 67.44% less overheads than the selective flooding and 80.2% less overheads than the regular broadcasting as shown in Figure 15.

Network broadcast storms cause redundant data which increase the network overheads and affects the overall performance of the network. More redundant data requires more broadcasts which consumes network resources and ultimately decreases the lifetime of the network. Solutions aiming at broadcast storm problem must be capable of providing lower redundancy in terms of data floating in the network during re-broadcast sessions. The proposed PSR algorithm is capable of handling this situation efficiently

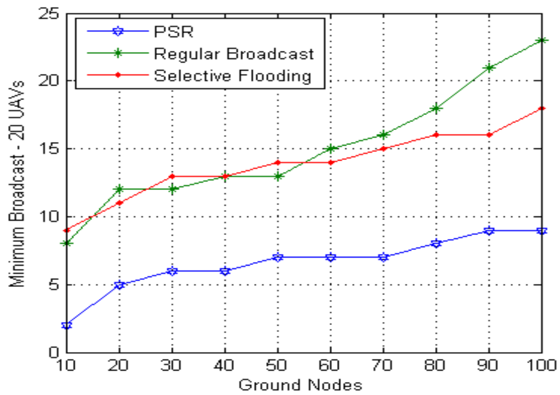

Figure 12: Broadcasts Vs Ground Nodes

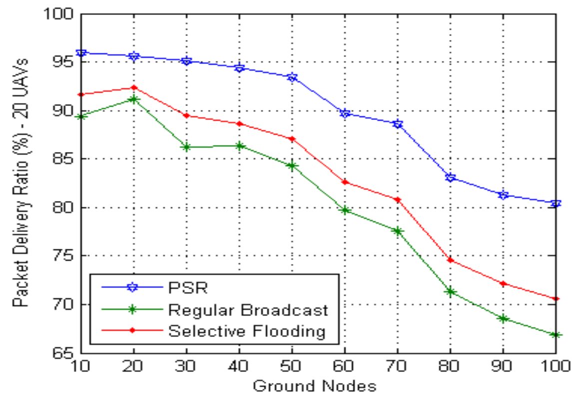

Figure 13: Packet Delivery Ratio Vs Ground Nodes

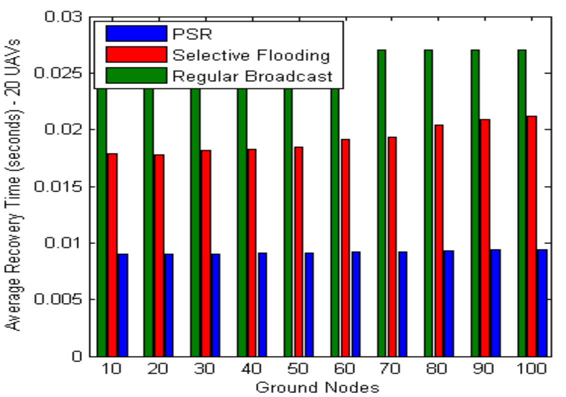

Figure 14: Link Recovery Time Vs Ground Nodes

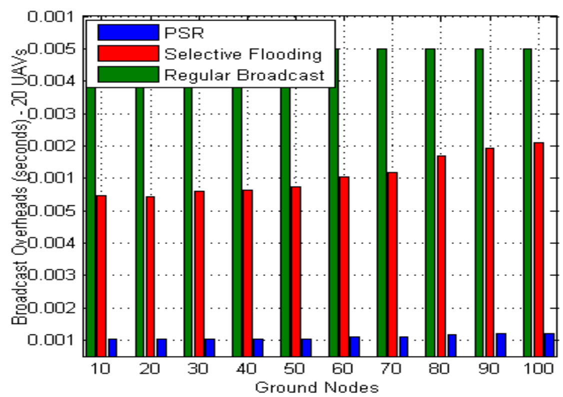

Figure 15: Broadcast Overheads Vs Ground Nodes

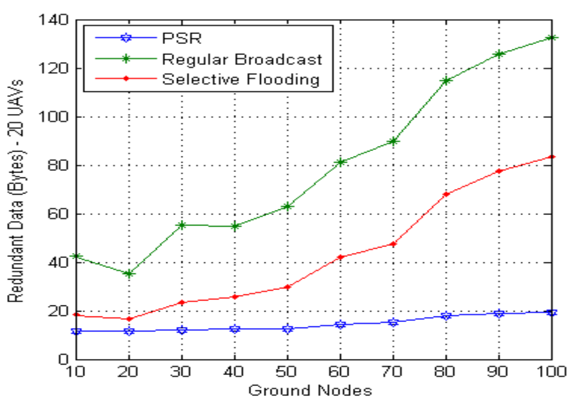

Figure 16: Redundancy Vs Ground Nodes

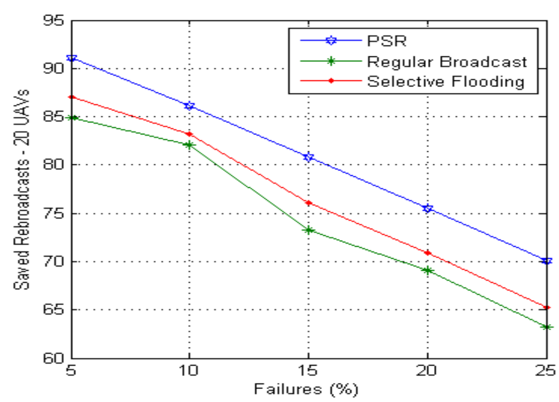

Figure 17: Saved Rebroadcasts Vs Failures (%)

as it caused 66.17% less redundancy than the selective flooding and 81.6% than the regular broadcasting approach. The comparative plot for redundancy caused over the network is shown in Figure 16. One of the most important metric for analysis of solutions proposed for broadcast storms is saved rebroadcasts. An approach that saves more rebroadcasts is efficient in handling data redundancies, and it save network resources from over consumption, thus, increases the network life time. Saved rebroadcasts are derived over ratio of difference between the actual receiver-transmitter links to the total receiver links. PSR saved 5.25% broadcasts in comparison with selective flooding and 7.7% in comparison with regular broadcasting. The analysis plot for saved rebroadcasts comparison is shown in Figure 17. Analysis proved that the proposed approach is capable of handling broadcast storm issue effectively over the coordinated network formed between the ground nodes and the aerial nodes. Better connectivity and improved transmission was attained using the proposed PSR algorithm.

5 Conclusion

Network operating in coordination with each other have tendency to often get disconnected due to node isolations or node failures. One of the major reasons for node failures is over-consumption of node resources. Node resources, if depleted before completion of transmission, can hinder the performance of the whole network. Broadcast storm is one of the reason that depletes the network resources drastically. Broadcast storm arising from data redundancy due to multiple broadcasts towards the same link requires more resources. However, these resources are used for processing of same data. An efficient approach based on the parameter sensitivity is proposed in this paper. The proposed approach forms a logical proximity graph operating over the derived sensitivity and link weights. These graphs allows selection of appropriate links for routing and do not cause any network partitioning. The proposed algorithm that is used for finding routes under this approach is termed as proximity-sensitivity routing algorithm (PSR). Analysis traced using simulations proved that the proposed approach is capable of handling issues related to broadcast storms, and it is capable of handling network partitioning issues that may arise due to non-satisfaction of thresholds defined for link quality parameters.

In future, work can be extended in realizing more enhanced approach towards network partitioning that can be integrated with proposed proximity-sensitivity routing (PSR) algorithm to form a more fault-tolerant network.

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