Efficient routing in multicast mesh by using forwarding nodes and weighted cost function

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Abstract

Multicast Mesh based Mobile Ad-hoc NETworks (MANETs) provide efficient data transmission in energy restraint areas without a fixed infrastructure. In this paper, the authors present an improved version of protocol SLIMMER developed by them earlier, and name it SLIMMER-SN. Most mesh-based protocols suffer from redundancy; however, the proposed protocol controls redundancy through the concept of forwarding nodes. The proposed protocol uses remaining energy of a node to decide its energy efficiency. For measuring stability, a new metric called Stability of Node (SN) has been introduced which depends on transmission range, node density and node velocity. For data transfer, a weighted cost function selects the most energy efficient nodes / most stable nodes or a weighted combination of both. This makes the node selection criteria more dynamic. The protocol works in two steps: (1) calculating SN and (2) using SN value in the weighted cost function for selection of nodes.

The study compared the proposed protocol, with other mesh-based protocols PUMA and SLIMMER, based on packet delivery ratio (PDR), throughput, end-to-end delay and average energy consumption under different simulation conditions. Results clearly demonstrate that SLIMMER-SN outperformed both PUMA and SLIMMER.

1. Introduction

Mobile Ad Hoc Networks (MANETs) are most helpful in situations which are power deficient and cannot have a fixed infrastructure, as in case of natural and manmade disasters. MANETs consist of mobile nodes, each of which also works as a router. Multicast mesh based routing creates alternate routes between source and destination reducing the bandwidth consumption, traffic and delay, supporting group-oriented applications and increasing robustness [1, 2].

However, this redundancy is obtained at a cost of increased energy consumed. So the need to provide services to customers while preserving energy is an important challenge for routing in multicast. As traditional routing cannot suffice to continuous changing topology of MANETs, another important challenge in mobile ad-hoc networks is to provide stable routes [3]. Several routing protocols have been proposed to maintain energy efficiency and link stability in ad-hoc networks [4, 5].

Link stability measures amount of time a link can withstand in a network while continuing to send data, without any breakage [6].

Various approaches were proposed for link stability in MANETs. Most of these use either node's mobility [7, 8, 9] or its residual energy to find stable links [10, 11].In some cases a combination of parameters was also used [4, 12]. Node Stability-based Routing used mobility degree of a node relative to its neighbours, to establish stable and sustainable paths [7, 8]. Another approach used link lifetime prediction method using transmission range and location parameters (position, speed and direction) of the sending node and neighbouring node [9]. A recent approach using both energy and relative velocity of nodes, for computing acceptability of a path from a multicast sender to a multicast receiver was given in [25]. Energy Efficient Lifetime Aware Multicast (EELAM) worked by selecting optimal intermediate nodes with maximal residual energy [10].

Link-stability and Energy aware Routing protocols (LAER) approach tried to optimize a route using link stability and minimum drain rate energy [11]. A routing strategy using energy-rich nodes to provide efficient route was proposed by authors in [12]. Another solution for optimization problem of the MANETs using transmission range and number of nodes was given in [13]. A reliable and energy-aware multicast ad hoc on demand distance vector (REA-MAODV) routing protocol was proposed which could find energy-efficient multicast routes from source node to a group of destination node[26]. Efficient power aware routing (EPAR) method proposed recently, selects nodes on the basis of residual battery power, and the expected energy consumed for forwarding data on a specific link[27].

It is evident from the literature, that a major challenge in case of MANETs is to provide an efficient stable route for energy restraint, continuously mobile nodes. The current paper proposes a mesh based multicast protocol called Stable Links in Multicast Mesh for Energy Efficient Routing using stable nodes (SLIMMER-SN) to meet these requirements. The major contribution of the paper is that unlike its predecessors it does not broadcast packets throughout the network, but selects an Energy Efficient Stable connected dominating set (EESCDS) to do so. The CDS [18, 19, and 20] is selected by using an algorithm based on self pruning algorithm given by Lim and Kim [22].The proposed protocol controls flooding and avoids redundancy, congestion, undue energy expenditure and relatively gives better link stability. Another important contribution is that the algorithm uses a weighted cost function which can favour selection of (a) energy efficient nodes in conditions requiring high energy consumptions and/or (b) stable nodes in highly dynamic conditions, by allocation of suitable

weights. Extensive simulations were carried out on ns 2.35 which showed that SLIMMER-SN outperformed both PUMA and SLIMMER in terms of PDR, throughput, delay and average energy consumed.The rest of the paper is organized as follows: Section 2 discusses the background of SLIMMER-SN and related studies; Section 3 presents the proposed protocol SLIMMER-SN; Section 4 presents the experimental results and Section 5 concludes the study and presents the future work.

2.   Related Work

Our protocol is close to Protocol for Unified Multicasting through Announcement (PUMA) [14] and Stable Links in Multicast Mesh for Energy Efficient Routing (SLIMMER) [15]. The protocol SLIMMER-SN uses the concept of a cost factor based on energy efficiency and stability of nodes to find efficient routes, which has been further detailed in the following sub-sections.

A.   Protocol for Unified Multicasting through Announcement (PUMA)

PUMA is a receiver initiated multicast mesh protocol. It uses the same multicast announcement (MA) for election of cores, for deciding the routes for sources outside a multicast mesh, to unicast data packets toward the group, and for maintaining mesh. It thus achieves a higher data delivery ratio with lower overheads.

Each node maintains a connectivity list for every multicast group, by storing the information from MAs which it receives from its neighbours. A multicast mesh is established, rooted at the core, with initially all receivers as mesh members. A non-receiver could be a mesh member if it lies on one of the shortest paths, from a receiver to the core. Data packets are forwarded to a mesh member in unicast manner, and then flooded within the mesh.An important constraint in PUMA is that the next forwarding nodes for construction of mesh, are selected on hop counts, which could result in link breaks if (i) the node moves away out of transmission range, as could be in high mobility network or (ii) if it becomes passive due to energy restraints. Further, flooding of data cause:

   (1) Congestion and packet loss and

   (2) Loss of energy in nodes employed in large scale indiscriminate flooding.

SLIMMER improves on PUMA by employing nodes which are energy-efficient to become mesh members.Although many different works were proposed for improving PUMA but they did not discuss much about energy efficiency or stability [16, 17].

B.   Stable Links in Multicast Mesh for Energy Efficient Routing (SLIMMER)

Stable Links in Multicast Mesh for Energy Efficient Routing (SLIMMER) was proposed by the authors as an energy efficient improvement over PUMA. Unlike PUMA, which only considers hop count as decision criteria for making mesh, only an energy efficient node can be a next hop in SLIMMER. SLIMMER uses the remaining energy of a node to be the measure of the energy efficiency of that node. In SLIMMER Ek >= Ethresh, is a condition necessary for a node k to be energy efficient where Ek is the remaining energy of the node, Ethresh is threshold energy selected for all the nodes in a network and is taken as a positive fraction of initial energy of the node.Nodes with least distance from core and with energy more than selected threshold energy are to be used as next hops.

So for SLIMMER the remaining energy E of a node k for a time period of t, is defined as:

$$Ek = Ekinit - Ekcons \qquad\qquad (1)$$

Where

Ekinit is the initial energy of a node k at time t

Ekcons is the total energy consumed by a node k

Given as:

$$Ekcons = Ektrans . nk\ trans + Ekrecv . nkrecv + Eksleep + Ekidle \qquad (2)$$

Where

Eksleep is the energy consumed by a node k in sleep mode.

Ekidle is the energy consumed by a node k in idle mode.

nk trans = no. of packets transmitted by node k in time t.

Ektrans= energy consumed by a node k in transmitting one packet.

nkrec = no. of packets received by k in time t.

Ekrec = energy consumed by a node k in receiving one packet

C.   Energy efficiency of a node

Energy efficiency of a node in this study, was measured in terms of the remaining energy as in SLIMMER. The current study decides energy efficiency of a node on the basis of its (i) distance from the core and (ii) residual energy.

Thus energy-efficient nodes are those with (a) shortest distance to the core and (b) and fulfilling the necessary condition of $E >= Ethresh$. This contributes in avoiding futile short-lived nodes for making links, which would die without contributing much to data transfer after consuming important energy. Thus increasing energy efficiency of the whole network. Another important contribution of using energy- efficient nodes is, that solely with the use of different Ethresh values for different conditional (simulation time and number of nodes) or performance parameters, the network could be improved easily [21].

D.   Stability of the node

Stability of a route at a given time can be measured by the stability of the nodes constituting the route for that given time period. The current protocol SLIMMER-SN aims to address the node stability in a network by taking the following factors:

a. *Transmission range*: Transmission Range (Rtx) represents the range within which a packet is successfully received if there is no interference from other radios. As transmission range decreases, it becomes difficult for nodes to reach receivers without more hops, while in case of high transmission range, requirement of more energy and increased interference deteriorates performance. So to get good performance an optimized value of transmission range should be chosen, we call it *TRopt* in the current study.

b. *Node density:* Node density in this study is taken as the number of neighbouring nodes. A low node density increases the unavailable intermediate routing nodes, whereas a high node density causes congestion. Also for a short transmission range,the increase in node density increases the performance, as increased number of hops helps a data packet to reach its destination. So an optimized value of node density needed to be chosen to get better performance; we call it *NDopt* in the current study.

c. *Node velocity*: An important factor causing frequent link breaks is high mobility of nodes, as it causes the node to move out of the sender's transmission range quickly, making the link

unstable and prone to break. In case of nodes moving with a very small velocity delay increased, so to get good performance an optimized value of node velocity needed to be chosen, we call it *NVopt* in the current study.

In the current study, the effects of these three parameters were considered for defining the stability of a node by a metric SN.

d. Defining SN

Assumptions made while calculating SN:-

1**.** Each node can find its transmission range (TR), neighbour density (ND) and node velocity (NV).

2. The values of TRopt, NDopt and NVopt found after initial set of simulations, were used later in the studies.

Stability for a node *u* at a time *t* is given as SN_u defined as a weighted function of w1, w2, and w3 such that

$$SN_u = w1+w2+w3 \text{ when TR= TRopt} \qquad (3)$$
$$\text{and}$$
$$SN_u = (w1 \text{ x } w2) + w3 \quad \text{in all other cases} \qquad (4)$$

Where w1, w2 and w3 are positive variable weight factors associated with transmission range (TR), node density (ND) and node velocity (NV) for a node *u* at any time *t*.

In this study the values of w1, w2 and w3 vary as follows:
  a.   w1=w2=w3=1 when TR= TRopt
  b.   w1= 1 if TR >= TRopt and -1 otherwise
  c.   w2= 1 if ND < NDopt and -1 otherwise
  d.   w3 =1 if NV<= NVopt and 0 otherwise

The values for w1, w2 and w3 were taken only as a representative value to show the effects of each respective parameter .

E. Cost function

The problem of selecting the most efficient route in a network depends on the energy efficiency and stability requirements of the network. However these two parameters cannot be maximised together in most cases, hence a trade-off needs to be decided upon. In case of energy deficient but comparatively stable network, it is essential to select energy efficient nodes to create route, while on the other hand in case of highly dynamic environment with energy efficient nodes, selection of stable nodes should be favoured.Another application would use available nodes, energy efficient and/or stable, to create routes. Thus a weighted cost function CF is defined in equation 5:

$$CFj= \alpha. (1/ Ei) +\beta. (1/ SNi) \text{ where } 1<= i < = n \qquad (5)$$

Where α is a weight associated with the reciprocal of energy efficiency of the node, Ei (residual energy of the node) and β is the weight associated with reciprocal of stability of the node, SNi (Stability node factor). Ei and SNi for a node i are calculated according to equation (1) and equations (3 and 4) respectively. These are stored as fields in a control packet stored as multicast announcement (MA) in the study.

Reciprocals have been used so that the objective functions of the proposed mathematical model could be minimized.The optimal solution of the model introduced above is Pareto optimal and gives an idea about the shape of the Pareto surface and trade off among the various

objectives [11].The user should choose appropriate values for the parameters α and β. In applications where energy efficiency is important or only energy efficient nodes are available α >> β, whereas for applications where maintaining links and reducing delay are important and energy efficient nodes are not available, β >> α.

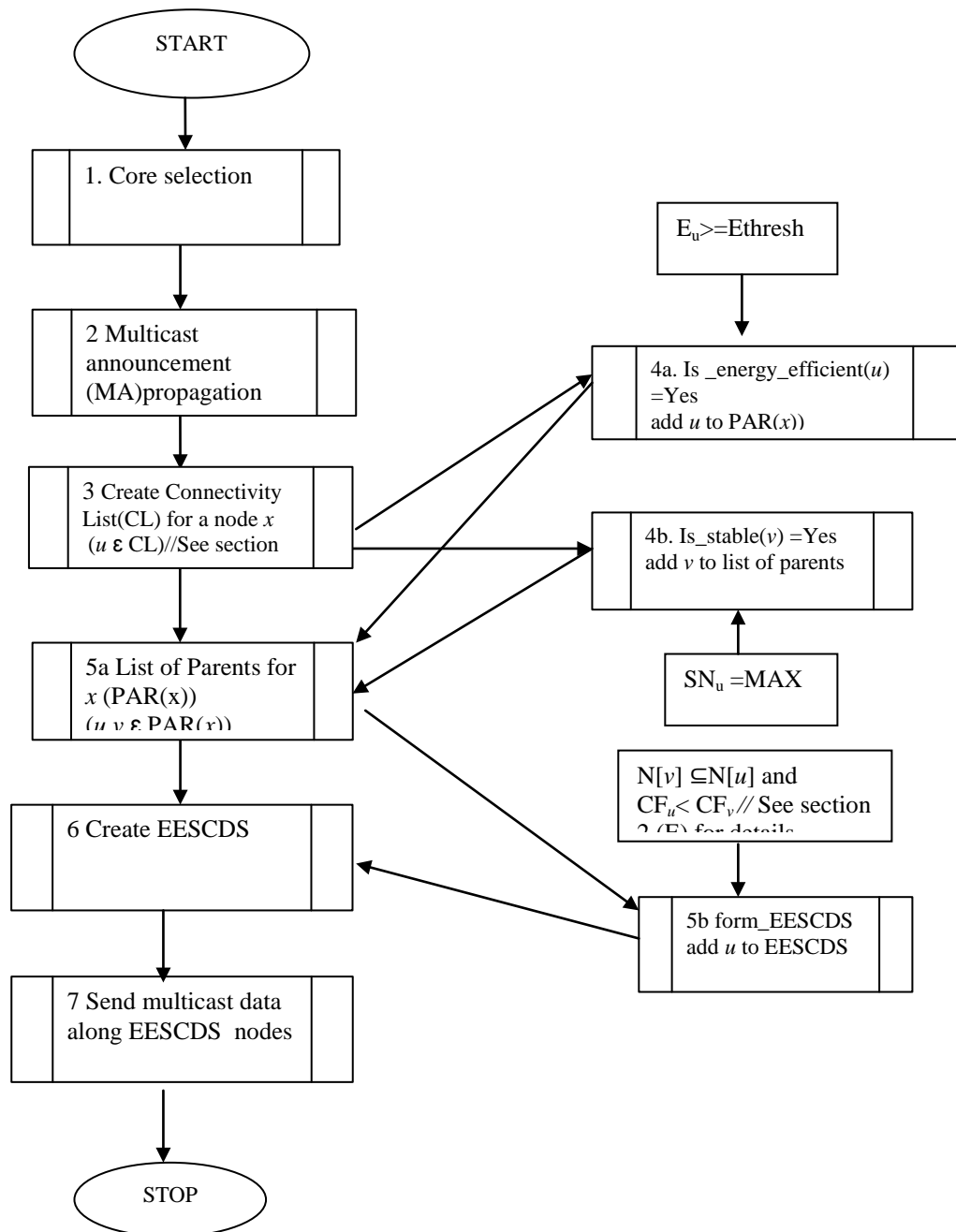## 3.   Stable Links In Multicast Mesh for Energy efficient Routing using Stable Nodes (SLIMMER-SN)

START

1. Core selection

$E_u >= Ethresh$

2 Multicast announcement (MA)propagation

4a. Is _energy_efficient(u) =Yes
add u to PAR(x))

3 Create Connectivity List(CL) for a node x
(u ε CL)//See section

4b. Is_stable(v) =Yes
add v to list of parents

5a List of Parents for x (PAR(x))
(u,v ε PAR(x))

SN_u =MAX

$N[v] \subseteq N[u]$ and
$CF_u < CF_v$ // See section
2 (E) for details

6 Create EESCDS

5b form_EESCDS
add u to EESCDS

7 Send multicast data along EESCDS nodes

STOP

Fig. 1. Block diagram for functionality of SLIMMER-SN

The flowchart in **Fig. 1** gives the functionality of the proposed protocol The algorithm includes the following blocks or predefined processes:(i)Is _energy_efficient(u) (ii)Is_stable(v) and (iii) form_EESCDS

The first receiver becomes the core and every receiver connects to the elected core, by using its address or the core id, by shortest paths.In case of more than one receiver, the one with the lower id is chosen as a node. The need of unicast messages is completely eliminated as SLIMMER-SN uses a single multicast announcement (MA) message to create and maintain mesh, election of cores and selection of routes. In PUMA the node with minimum hop count to the core is selected as the parent, or the preferred neighbour to reach the core. However these links may die out when nodes constituting them die out, due to lack of energy causing frequent link breaks. Also in case of PUMA, once a multicast data reaches a mesh member, it is flooded along the whole mesh causing redundancy, congestion, energy loss and link breaks.

Thus SLIMMER-SN improves upon its predecessors in:

1.   *Parent selection*: In case of availability of more than one node at shortest distance, the energy of a node and its stability together with hop count from the core, are used to select parents.

2.   *Data transmission:* A data packet is not flooded in the mesh, but sent across a set of forwarding nodes, this avoids the overheads incurred during flooding. Further the forwarding nodes are selected on account of (1) energy efficiency and (2) node stability. This leads to stable and energy efficient route selection.

The activities of SLIMMER-SN can be summarised as: The core sends MA, to create mesh and as the MA propagates a connectivity list is created at each node which stores data from all recent MA it receives. Out of all entries in the list, a node selects nodes at the shortest distance which are energy efficient and/or stable, as its parents depending on network conditions.The data packets are not flooded across the mesh but the protocol selects a set of forwarding nodes, for controlled data transmission.

3.1 Network Model

The network model can be given as an undirected graph $G = (V, E)$ where V is the set of vertices and E is the set of bidirectional edges. Since SLIMMER-SN uses a structure based on a set of forwarding nodes, we define a few theoretical concepts before their usage further in the paper.

Definition1. Given a graph G, Dominating Set (DS) is a subset $D \subseteq V$, such that for V, such that for every vertex v ε V, either v ε D, or v has a neighbour in D.

Definition2. Connected Dominating Set (CDS): Given a graph G, a Connected Dominating Set (CDS) is a subset $D \subseteq V$ which satisfies the following two conditions.

•   *D is a DS*

•   *For every two nodes u and v in D there exists a path between u and v such that all intermediate nodes belong to D*

Definition3. Graph G has a set of nodes V, such that V= F U P, and F = {s} U L U R where
   a)   F is set of forwarding nodes, which receive and propagate packets
   b)   P a set of passive nodes, which only receive packets do not propagate them further.
   c)   L is a set of link nodes lying on the path between source and destination.
   d)   *s* is the source and R is the set of receivers.
        F and P satisfy the following conditions:
   e)   All nodes in F and P receive packets.

      f)   Nodes in F propagate packets.
      g) $\forall$ u $\in$ P has at least one forward node as its neighbour,
      h)   Every forward node is connected to the source node via a path consisting of forward nodes only.

Energy Efficient Stable CDS (EESCDS): Given a graph G (V, E, and R) where f is a function which assigns weight to all the nodes f: V → R+. In case of our study, the energy efficiency and stability of node are assigned weights. EESCDS ensures that a node with lower weight than neighbours must be a member of CDS, keeping the total cost factor minimized.

Theorem 2. For v $\in$ V, N (v) denotes neighbour set, and N (v) = {u | (u, v) $\in$ E} and a broadcasting ensures coverage, if every node receives the broadcast packets; that is, V − F $\subseteq$ N (F), where N (F) = U $_{v \varepsilon F}$ N (v), and v is a forwarding node and N (F) is a set of union of all neighbours of v.

Lemma1: EESCDS ensures coverage

Proof: The proof is presented as a contradiction so let us assume that the CDS created does not provide full coverage thus there are nodes which do not receive the packet as they have no neighbour in the forwarding set.; we call such nodes unvisited node or UV.

For any given network represented as a graph G (V, E) with *s* as the source node let FN be the set of forwarding nodes, which both receive as well as carry the packets. Also, let PN be the set of passive nodes, which only received the packets, but did not carry them to UV. Apparently PN ≠ Ø, because if there were no passive nodes, then the graph would not be connected and UV nodes would be separated from source node. Thus UV = V – FN - PN and UV ≠ Ø [as per assumption].So as in **Fig. 2**, we have an unvisited node *x* which did not receive a packet, because the neighbouring node *w* with the lowest CF value, is a passive node. Also by definition since each passive node should have at least one forwarding node as a neighbour, so let there be a node *y* as a neighbouring forward node to *w; y* ε N (*w*) and *y* ε FN. According to our definition of EESCDS, a forwarding node should have the minimum CF in the neighbourhood so CF*y* should be less than CF*w*. However, as per our assumption w has the least CF in the neighbourhood; this contradicts our choice of *y* as a forwarding node for energy efficient stable CDS. Hence, our assumption is wrong and *w* should be a member of FN. Thus EESCDS implies, that there is no unvisited node *x* or U = V −F −N (F), is empty. Explanatory diagram for the proof, is given in **Fig. 2**. Let f's represent forwarding nodes.
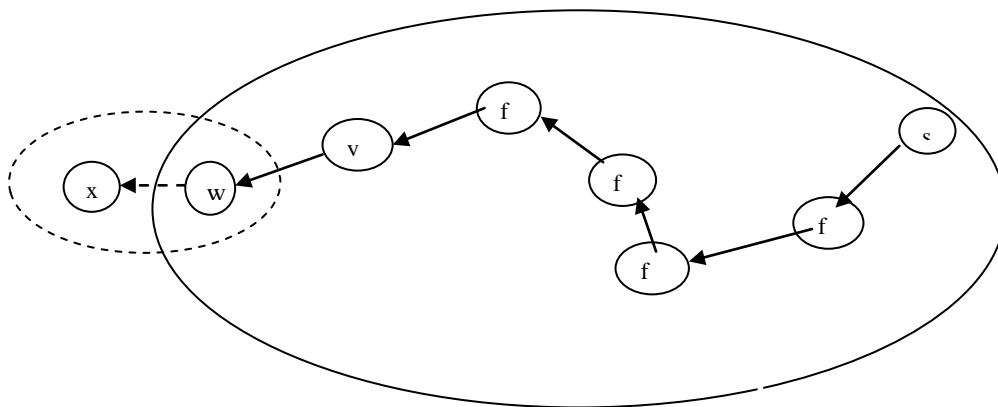

Fig. 2. EECDS ensures coverage

3.2 Multicast Announcement

SLIMMER-SN uses a multicast announcement (MA) for creating and maintaining mesh, selection of core and route. The structure of MA in SLIMMER-SN is given in **Fig. 3**.

Mesh member	SN	Energy
Core id		
Group id		
seq number		
parent		
Distance to the core		

Fig. 3. Structure Multicast Announcement SLIMMER-SN

The fields specified by a MA are as follows:
- Core ID: core ID in the best multicast announcement
- Group ID: group ID in the best multicast announcement
- Sequence number: sequence number in the best multicast announcement
- Distance to core: One plus the distance to core in the best multicast announcement
- Parent: The neighbour from which it received the best multicast announcement
- Mesh member status: whether a particular node is a mesh member
- SN: SN value of the node
- Energy: remaining energy value of node

Mesh member status: A node sets its status to true if it is a mesh member when
- It is a receiver
- Non-receivers consider themselves mesh-members if they have at least one mesh child in their connectivity list. A neighbour in the connectivity list is a mesh child if :

 (1) its mesh member flag is set, (2) the distance to core of the neighbour is larger than the node's own distance to core, and (3) the multicast announcement corresponding to this entry was received in within a time period equal to two multicast announcement intervals

First two conditions ensure that if a node has a mesh child then it lies on a shortest path from a receiver to the core and should therefore be a mesh member. Condition 3 is used to ensure that a neighbour is still in the neighbourhood.

Multicast announcement (MA) propagation

A node that considers itself to be the core of a group transmits multicast announcements periodically for that group. As the multicast announcement travels through the network, it establishes a connectivity list(CL) at every node which stores the data received from all the multicast announcements from its neighbours, with the time when it was received. Successive MAs from the same core have a higher sequence number; the node keeps only one most recent entry in its connectivity list from a particular neighbour. It then generates its own multicast announcement, based on the best entry in the connectivity list. Nodes which are neither energy efficient nor with maximum stability node index, SN will not be considered for parenthood

After selecting the best multicast announcement, the node generates the fields of its own multicast announcement. In case of core the parent field is kept as invalid address and distance to core as zero. **Fig. 4** gives the propagation of MAs from neighbouring nodes to a node 5.

Say the connectivity list for node 5 has entries for its neighbours 4, 8 and 11 respectively given in **Table 1**. While all 4, 8 and 11are at the same distance from the core, 4 and 8 are energy efficient and node 11 has highest SN, value so all are prospective candidates for parents

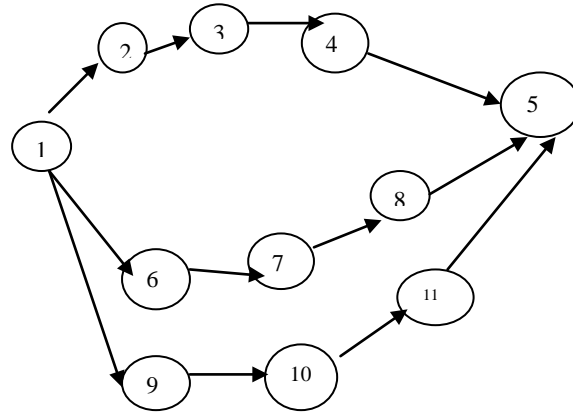depending on the prevailing network conditions.**Table 1** gives connectivity list for the node 5.

Fig. 4. Propagation of Multicast Announcement

Table 1. Connectivity list of node 5 (Core ID = 1, Group ID = 224.0.0.1, Seq. No. = 79)

Neighbor	Multicast announcement				Time (ms)
	Distance to core	**Parent**	**Energy status**	**SN**	
4	3	3	99%	2	12552
8	3	8	88%	1	12180
11	3	10	20%	3	12182

After waiting for some time, to collect updated MAs from its neighbours node 5, makes its own MA. There can be more than 1 parent for a node and in that case MA shall propagate through all parents.

3.3 Mesh Establishment and Maintenance

A mesh is established by all shortest path routes between a source and receiver pair. MA is used to create and maintain this mesh which excludes energy deficient and unstable nodes. After receiving of MA each node updates its connectivity list and selects the best entry or the parent(PAR)

3.4 Multicast data packets

In most of multicast mesh protocols, when the data packet reaches a mesh member, it is flooded within the mesh, and nodes maintain a packet ID cache to drop duplicate data packets, while in SLIMMER-SN cost function is used to decide the forwarding set, which would propagate data rather than flooding it throughout all the routes in the mesh. This cost function tradeoff between parameters associated with energy efficiency and stability. So data transmission in SLIMMER-SN follows the following steps:
- When x a non mesh member node receives multicast data packet, it unicasts the packet to a mesh member according to conditions given in 3.2.

- When x is a mesh member, it determines its forwarding set F and transmits the data packet to members of F.
- A non member of forwarding set doesn't retransmit the packet further but receives it.

4. Experimental Results and Analysis

To demonstrate the effectiveness of SLIMMER-SN, two sets of comprehensive simulations were performed on NS-2.35.

1. The first set of simulations was performed to (1) measure the effect of transmission range (ii) node density and (iii) node velocity on performance metrics and (2) find the values of TRopt, NDopt and NVopt.

2. The second set of simulations was performed to compare the performance of PUMA, SLIMMER and SLIMMER-SN under varying number of nodes.The results of first set of simulations have been used for the second set of simulations. Since performance improves with increased stability, the performance metrics PDR, Throughput, Delay and Average energy consumed were taken as a measure of stability for this study.PDR is the ratio of received packets to sent packets (including retransmitted packets). Throughput is the number of packets received per unit time. Delay gives the time latency between a packet sent to the packet received. Average energy consumed is a measure of energy consumed by each node. Assumptions:

- In this study maximum transmission power used is (Pt) = 0.28183815W, that can cover a maximum fixed transmission range of 250 m.
- The study further assumes that the transmission range and the carrier sensing range are identical, a packet if sensed, can be received [23].
- Transmission ranges were set by taking different values of receiving threshold (Rx) by modifying ns/indep-utils/propagation/ threshold.cc provided with the ns source files.
- All nodes are assumed to be energy efficient for Ethresh = 30% of initial energy [24] (for this study Ethresh=.3J).Initial energy in this study is 1 J.

4.1 Experiment 1 to demonstrate relation between TR, ND and NV

Experiment 1 was carried out to find the effect of parameters: transmission range,node density and node velocity on performance of the network.Case1 discusses the effects of only TR on performance whereas, Case2 studies the dual effect of TR and Node density. For the experiment purposes the total number of nodes is taken as the node density, as the node density will vary directly with number of nodes Case3 is a study about the dual effects of TR and Node Velocity.Simulation scenario for the first set of experiments given in **Table 2**.

Table 2. Simulation scenario for first set of simulations

Parameter	Value	units
Total Nodes	100, 200,300,400,500,600,700,800,900,1000	-
Transmission range	50,75,100,125,150, 225, 250	m
Node velocity	5,10,15, 20, 25,30	m/s
Ethresh	0.3	Joule
Simulation Area	1000 x 1000	M^2
Simulation time	100	sec

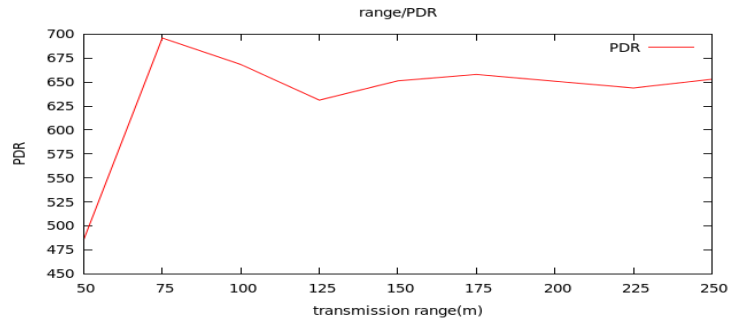*Case1*. Results for effect of transmission range on (a) PDR (b) Throughput and © Delay are given in **Figs. 5-7** respectively.

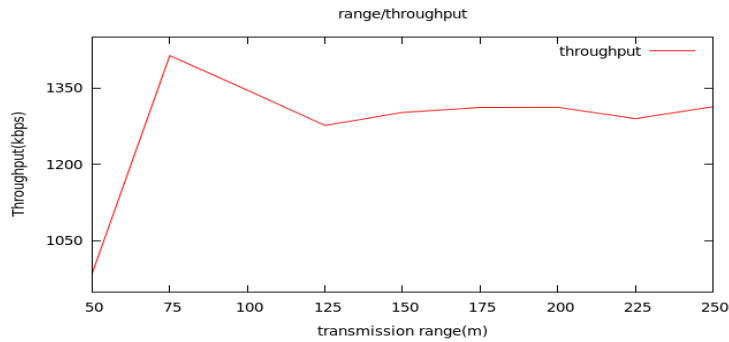**Fig. 5.** Effect of Transmission range(TR) on packet delivery ratio(PDR)

Fig. 6. Effect of Transmission range (TR) on throughput
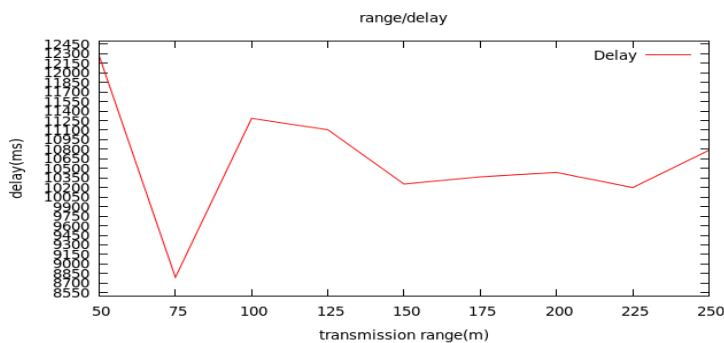

Fig. 7. Effect of Transmission range (TR) on Delay

It could be seen that when the transmission range is very small (50 m) the nodes are practically isolated with small communication overlap between sender and receiver, as a result the delay is more and PDR and throughput less. When the range increases (75m) and the receiver and sender communicate directly, the values of all parameters improve up to a certain level.Large transmission range(>75m) causes more interference, more energy consumption which results in nodes dying out. Larger values of TR do not add to the performance as the nodes do not add to efficient routes but just add to congestion.An optimum level of transmission range which gives best performance in our case, we term it as **TRopt,** was found at 75m.

Case2. Results and discussion for the dual effect of transmission range and Node density.
The effects of node density (ranging from 100-1000 nodes) were observed for four different transmission ranges:

- When transmission range was very low (50m)   for Rx= 7.69113e-08
- When transmission range was optimum or **TRopt** (75m) for Rx =3.417817e-08(as per previous result).
  - When transmission range was high (150m) for Rx= 2.81e-09.
- When transmission range was highest (250m) for Rx=3.65262e-10 (for transmission power=.28w).The results are shown in **Figs. 8- 10**.
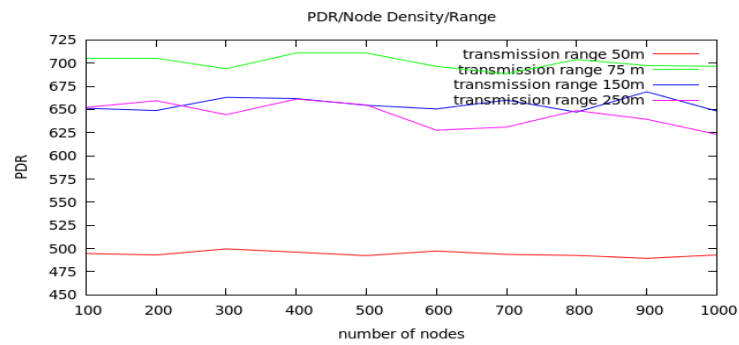
Fig. 8. Effect of TR and   Node density on PDR
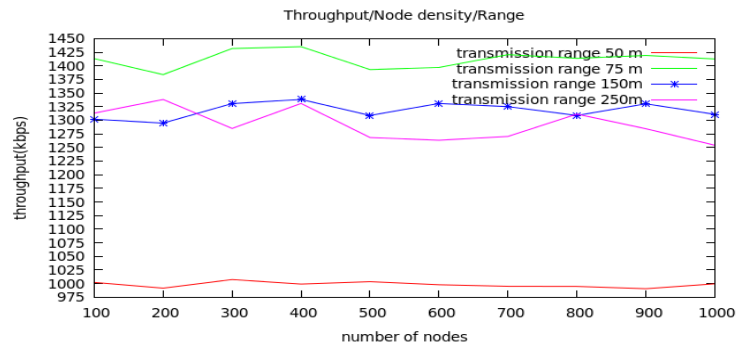
Fig. 9. Effect of TR and Node density on throughput
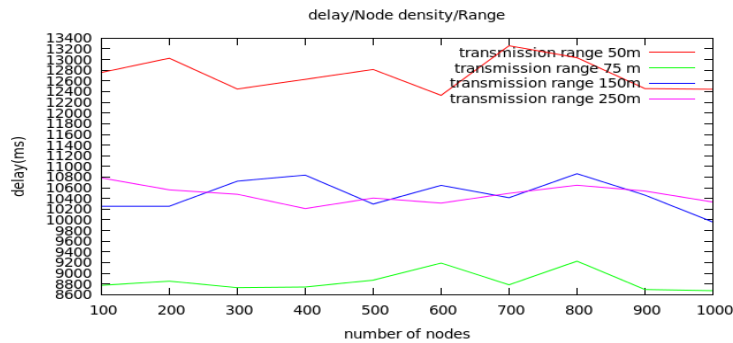
Fig. 10. Effect of TR and Node density on delay

For very low transmission range (50 m) the increase in the number of nodes, increases the throughput, as more relay nodes are available, however, it does not affect the PDR, the reason could be that receivers lie far on the periphery and all sent packets cannot be received. Also for low transmission range more hops are needed till destination, this increased hop count increase the delay.For an optimum range (75 m) PDR and throughput increase and delay decreases as more intermediate nodes are available and nodes can communicate more freely. However, after 400 nodes further increase in the number causes congestion and decrease in performance. With a further increase in transmission range (150 m) the PDR and throughput value maintain good values.When the transmission range is increased to the highest limit of the transmission power (250 m) PDR and throughput decrease as control packet traffic, interference and energy consumption increase. Also, as the number of nodes increase availability of more relay nodes, cause a decrease in delay, but a further increase of around 700 nodes cause link breaks, due to congestion, and delay increases.

Case 3. Results and discussion for the dual effect of transmission range and Node velocity are given in **Figs. 11-13** as in previous experiment.
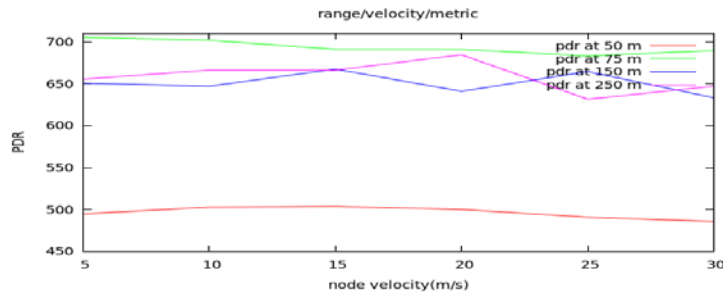

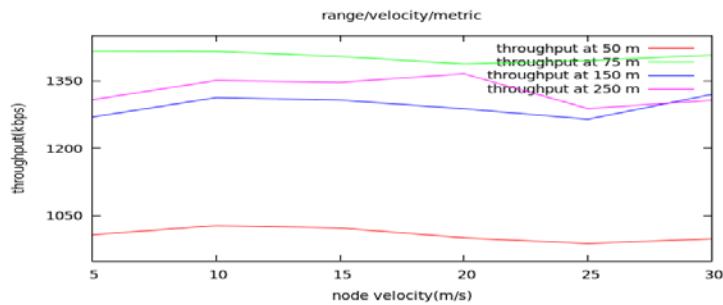**Fig. 11.** Effect of TR and Node velocity on PDR

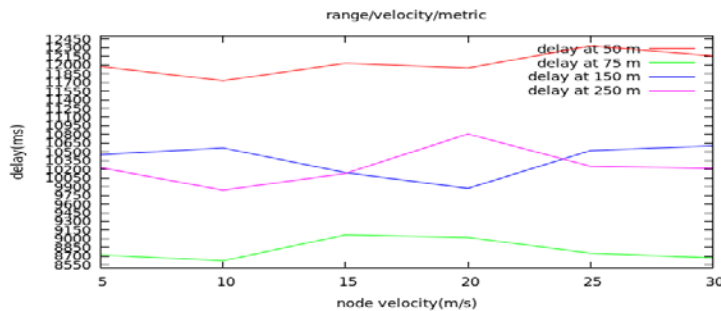**Fig. 12.** Effect of TR and Node velocity on throughput

Fig. 13. Effect of TR and Node velocity on delay

For a very small transmission range (50 m) PDR and Throughput are stable, marginally dipping at high velocity. The reason could be that higher mobility, although increases chances of more nodes coming in contact, but the nodes do so with low communication interval.

At a long transmission range (150 m) PDR follows the irregular pattern while throughput follows the same pattern as in case of small transmission range, as availability of nodes varies. For ranges at the highest limit of transmission (250 m in this study) throughput and PDR increases with increase in node velocity(up to 20 m/s) as nodes travel faster to reach destination.The availability of faster moving relay nodes decreases the delay.A further increase in velocity results in link breaks as communication overlaps between nodes decreases.

At an optimized range (75 m): All performance parameters give good values and remain stable even with an increase in velocity. After around 10m/s the performance starts falling for this TR so we take **NVopt** as 10m/s for this transmission range in this study.

As can be observed the results justify the general observations.

The results after experiment 1 (i) measured the effect of all the selected parameters energy, transmission range, node density and node velocity of performance metrics effected by link stability and (ii) derived the optimal values of all the parameters .

4.2 Experiment 2 to compare the performance of PUMA, SLIMMER and SLIMMER-SN

The performance of PUMA, SLIMMER and SLIMMER-SN was compared for packet delivery ratio.throughput, delay and average energy consumed.The comparison was done for two cases, case 1 for varying number of nodes and case 2 for varying simulation time.
The simulation scenario for experiment 2 is given under **Table 3**.

Case 1. Results for PDR, throughput, delay and average energy consumed for increasing number of nodes are given in **Figs. 14-17**.
Assumptions
1.   The set of simulations in experiment 2, use the results obtained in the first.
2.   For SLIMMER and SLIMMER-SN Ethresh= 30% of initial energy [24].
3.   TR= TRopt, NV = NVopt [as result of experiment 1].
4.   For the present study $\alpha = \beta =0.5$ was taken (equal weight to energy efficiency and stability).

Table 3. simulation scenario for second set of simulations

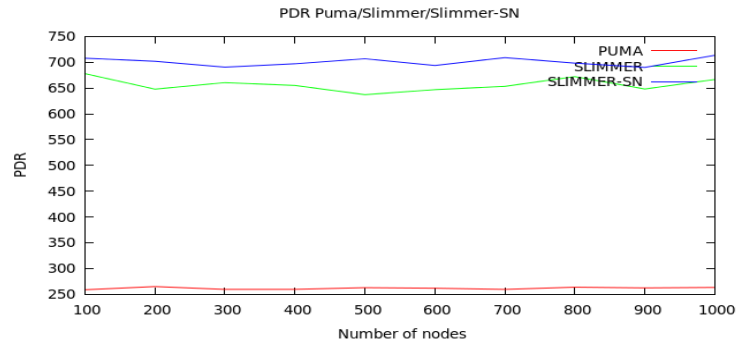| Parameter	Value	units
Total Nodes	1. 100, 200,300,400,500,600,700,800,900,1000 2. 100	-
Routing protocols	PUMA,SLIMMER and SLIMMER-SN	-
Transmission range	75(TRopt)	m
Node velocity	10(NVopt)	m/s
Initial energy	1	Joule
Ethresh	0.3	Joule
Simulation Area	1000 x 1000	m^2
Simulation time	1. 100 2. 100, 200,300,400,500,600,700,800,900,1000	secs

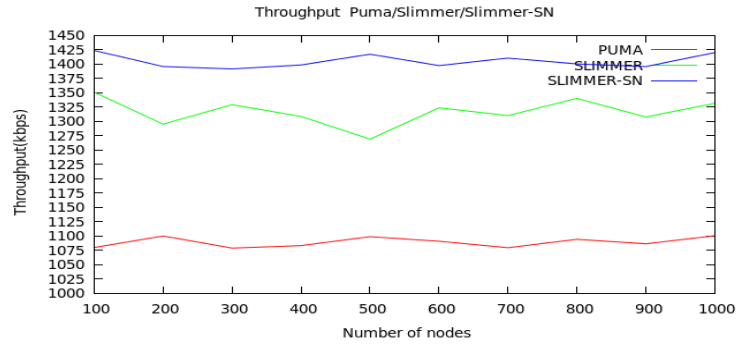**Fig. 14.** Comparative PDR for PUMA, SLIMMER and SLIMMER-SN with number of nodes

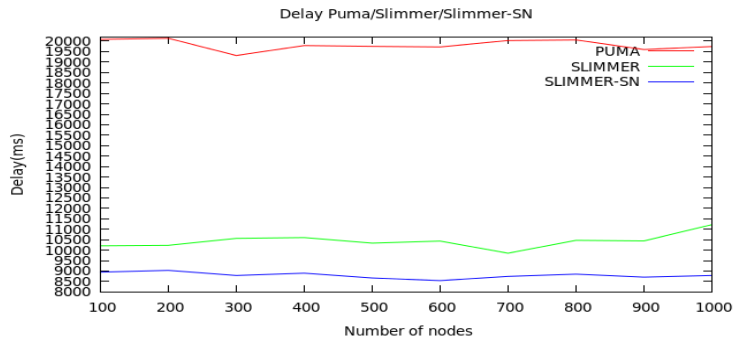**Fig. 15.** Comparative throughput for PUMA, SLIMMER and SLIMMER-SN with number of nodes

Fig. 16. Comparative delay for PUMA, SLIMMER and SLIMMER-SN with number of nodes
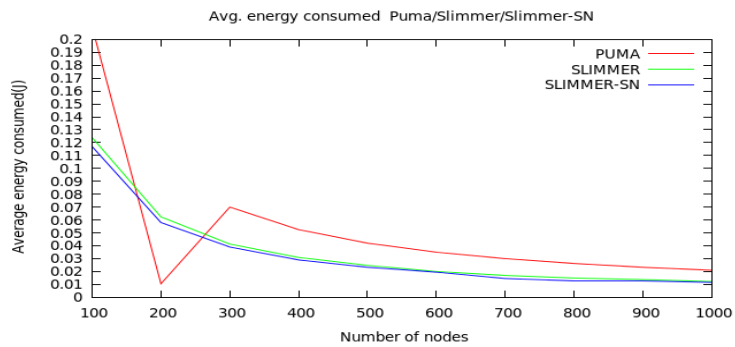

Fig. 17. Comparative avg. energy for PUMA, SLIMMER and SLIMMER-SN with no. of nodes

SLIMMER and SLIMMER-SN both use energy efficient nodes so their average energy consumed is same but better than PUMA.With increase in the number of nodes, congestion increases, but for SLIMMER and SLIMMER-SN this also means more energy efficient nodes, thus the detrimental effect is taken care of.Delay increases in PUMA as links break and new links are established, in SLIMMER for a high number of nodes around 800, congestion overpowers the requirement of energy efficiency as new nodes do not add to stability but increase traffic. SLIMMER-SN outperforms both as it decides dynamically and uses energy efficient or stable nodes whichever are available.

Case 2 : Results for PDR, throughput, delay and average energy consumed with increasing simulation time are given in **Figs. 18-21**.
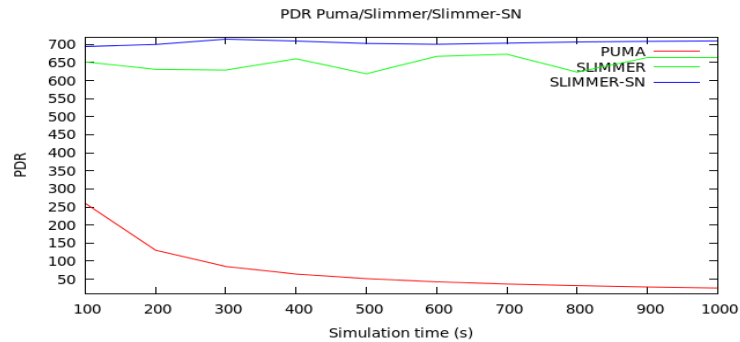

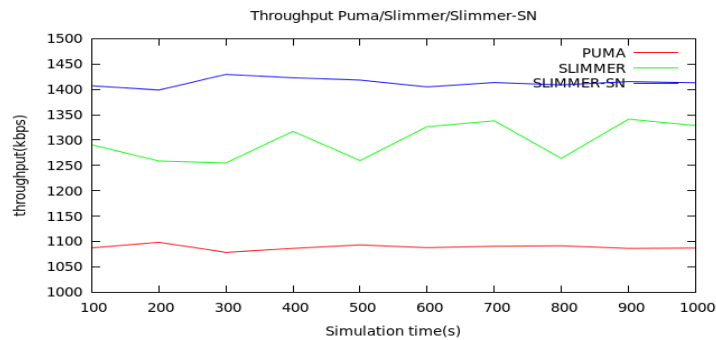**Fig. 18.** Comparative PDR for PUMA, SLIMMER and SLIMMER-SN with simulation time

Fig. 19. Comparative throughput for PUMA, SLIMMER and SLIMMER-SN with simulation time
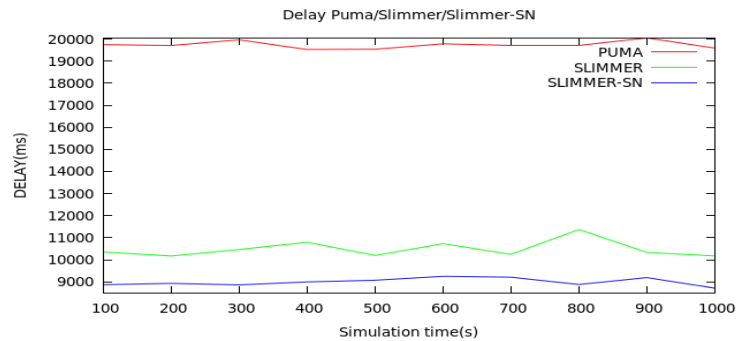

Fig. 20. Comparative delay for PUMA, SLIMMER and SLIMMER-SN with simulation time
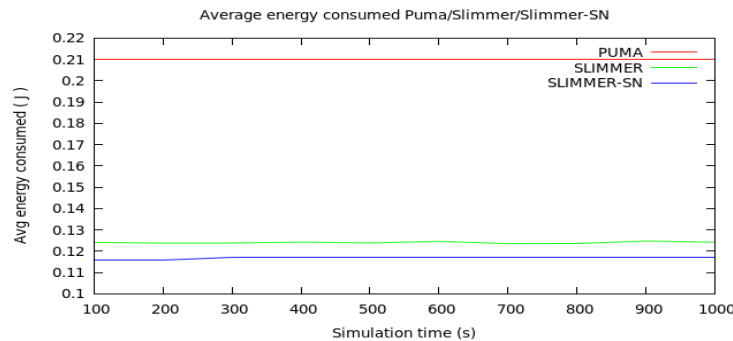
Fig. 21. Comparative avg. energy consumed for PUMA, SLIMMER,SLIMMER-SN with simulation time

For PUMA as nodes lose energy with time, availability of energy efficient nodes in PUMA decreases, so PDR decreases with more frequent link breaks. This causes irregularities in PDR for SLIMMER. However, energy efficient nodes in case of SLIMMER help the network in stabilising after retransmissions. In case of SLIMMER-SN, when/if energy efficient nodes are not available, the stable nodes are chosen to form links, and vice- versa; thus PDR and throughput in this case show considerable improvement over the other two protocols. In case of throughput for PUMA, the effect is not that pronounced as retransmission of packets do not affect the throughput. SLIMMER and SLIMMER-SN follows the same pattern as that for throughput. Delay and average energy show similar behaviour with varying time.
Table 4 given below gives consolidated results for both the cases.

Table 4. Consolidated outcomes

	PUMA	**SLIMMER**	**SLIMMER-SN**
PDR	Lowest	Good	Best
Throughput	Lowest	Good	Best
Delay	Highest	Low	Lowest
Avg. Energy consumed	High	Low	Low

5. Conclusion & future work

   MANETs face two important constraints of limited battery and frequent link breaks, both of which are taken care of in the proposed protocol. The proposed protocol SLIMMER-SN gives much better performance than both PUMA and SLIMMER, as nodes making mesh are energy efficient with maximum node stability. However the values of optimum transmission range, node density, node velocity, alpha and beta have been taken as per the results of our experiments and so these values may differ according to different network applications. The future work includes studying the effect of the speed at which the node drains the battery, on route stability and energy efficiency computation.Further, only some of the performance parameters have been compared in the current study, however there are various other parameters like packet size, jitter etc which also play very important role in determining efficiency of a protocol. Authors plan to compare and analyze some of the other performance parameters as a part of future work.An interesting area of research to analyze the failure situation of the protocol and applying the research to other areas.

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