J.Natn.Sci.Foundation Sri Lanka 2015 43 (3): 199-208
DOI: http://dx.doi.org/10.4038/jnsfsr.v43i3.7948

RESEARCH ARTICLE

Using animal communication strategy (ACS) for MANET routing

T. Manimegalai[1*], C. Jayakumar[2] and G. Gunasekaran[3]
[1] *Department of Computer Applications, SSN College of Engineering, Chennai, Tamil Nadu, India.*
[2] *Department of Computer Science and Engineering, RMK Engineering College, Kavaraipettai, Tamil Nadu, India.*
[3] *Meenakshi Engineering College, Chennai, Tamil Nadu, India.*

Revised: 12 September 2014; Accepted: 22 January 2015

Abstract: A mobile ad-hoc network (MANET) is a network of wireless nodes with high mobility. Mobile nodes change their position quickly in any direction and speed, and follow an infrastructure-less network. Although there are many mobility models and protocols available to find the path between any two nodes, the challenge in retaining the path still remains unchanged. In general, a permanent path between any source and destination does not exist because of the node mobility. Path retention is essential for certain applications like in the military, disaster and rescue operations where an infrastructure-less network like MANET is only feasible. In this paper an algorithm named 'Animal Communication Strategy (ACS)' is proposed to improve path construction and retention based on animal behaviour. Most of the time animals are found aggregated in the form of clusters. The cluster may undergo dispersal, reformation and reunion due to sudden changes. Each and every animal, who is aware of the changes, will immediately take the responsibility of communicating with their neighbours in the cluster. This impressive and cooperative behaviour of animals was adopted in the ACS algorithm. ACS algorithm is tested for performance using NS2 simulator. The results show a significant improvement with ACS for the metrics packet loss, delay and overhead when compared to the existing protocol in MANET routing.

Keywords: Animal communication strategy, DSDV, mobile ad-hoc network, path, routing, wireless nodes.

INTRODUCTION

A mobile ad-hoc network (MANET) is a network of wireless nodes with high mobility. MANET is an infrastructure-less network; hence each and every node acts as a host and also a router. Because of this mobility pattern, path breakdowns occur more frequently. Whenever there is a link failure, change of a path or selection of the next available path out of multiple paths are done. Path breakdown during transmission should not be entertained as it may result in data loss.

In general, path construction is done based on the availability of a node at the time a request is sent from the sender. The node that is selected in a path will not be concerned about the path break due to its mobility out of that transmission range. This may happen after the transmission or during transmission or even immediately after the path is found and before transmission begins. Predicting the mobility pattern of the other nodes is not easier because it is beyond the control or knowledge of a node.

A study on animal behaviour was done in order to learn how they communicate in different situations like predation, attracting mates, scaring off predators or orienting themselves. As this is similar to the nature of communication involved in MANET, a trial on routing was done with the algorithm ACS based on animal behaviour, and the results were found to be attractive compared to the existing protocols.

In this paper the communication strategies in a flock of birds, a school of fishes and a colony of bats are analysed.

Communication in a flock of birds

Birds communicate with each other using a call note or a song. Different species of birds have different call notes for different messages. The call notes sound like a screech, caw or click in larger birds and sound like a chip, chirp or peep in smaller birds (Hinde, 1969; Kroodsma

* Corresponding author (manimegalait@ssn.edu.in)

& Miller, 1982). This can be similar to a strong signal required to pass a note to a node at a longer distance. Even a lighter signal is enough for a node nearby in MANET. In a flock of birds flying in a specific pattern like an English letter V in reverse, the bird flying in front will come to the last row after a period of time when it becomes tired of facing the force of the air. Then a bird from the pair of birds in the last but one row will take the lead and the cycle continues till they reach their destination. The communication of when the leading bird should move back and synchronously a bird from the last but one pair moving to the front is quite interesting. Before the leading bird starts leaving, it communicates with the pair behind, and the same is repeated till the last but one pair. The initiation of this communication is done by the leading bird, which wants to move back as only this bird knows that it wants to retire from the leading position. The same way, when a bird finds a predator, it will inform the flock that they should move to a safe place and can gather again after a call note is received that they are out of danger. The other birds do not predict the movement of the leading bird or the bird moving away from a predator, rather the leading bird itself will intimate the information to their flock (Hinde, 1969; Kroodsma & Miller, 1982; Nachtigall & Moore, 1998; Wheye *et al*., 2012).

Communication in a colony of bats

Studies have shown that communication in bats is very complex and intricate. Because of the blindness or near blindness, bats rely on sonar or echolocation to detect the location of objects around them or to communicate (Altringham, 1996; Kunz & Fenton, 2003). Echolocation is an important tool for bats and interestingly, most bats have a distinct style of their own when hunting for food, navigating territory and locating predators. Little brown bats make calls to communicate with each other. An example of such a call is when two bats are flying on a collision course during feeding (Rountree *et al*., 2002). The similarity between the mobile nodes in MANET and the bats in a colony is that both cannot see their peer ends. Hence the communication mode of bats can be followed with mobile nodes. Similar to the method used by bats to pass information to other bats through a signal, the mobile node can also pass a signal or control/update packets to communicate the mobility information to the other nodes within the transmission range.

Communication in a school of fishes

The communication strategy of fishes is even more interesting because their mobility is more dynamic as compared to other animals. In spite of this, the organisation is well structured in their community; hence they are able to manage with their communication without much complexity. The communication is very fast, since within no time they scatter during danger, and gather during need. In their school, they follow the instructions of the informer with proper synchronisation either to meet together or to disperse apart immediately (Kramer, 1990; Evans, 1998; Zelick *et al*., 1999; Dugatkin, 2009). As this scenario resembles the essential quality required and the challenge to be met in MANET, a similar communication strategy between nodes can be adopted as in fishes.

In summary, the communication patterns in most animals are similar to the initiation of passing information, starting from the animal that knows what has to be communicated and when. The animal, which moves out of the group will inform the others, and the same way will inform in order to gather again. The same strategy can be adopted in MANET environment where the nodes moving out or coming into the transmission range can itself inform the others nearby because only they know their mobility better than the others. This can help other nodes to update their routing table.

Many mobility models and routing protocols are already available for communication in MANETs. The mobility pattern of the mobile nodes are determined using models such as random direction mobility model, random way point model, random walk mobility model, reference point group mobility model, free way mobility model, Manhattan mobility model, random Gauss-Markov model, random drunken mobility model, community mobility model and group force mobility model. The path finding is done through routing protocols such as destination-sequenced distance-vector (DSDV), wireless routing protocol, optimised link state routing in pro active, dynamic source routing (DSR), ad hoc on-demand distance vector (AODV), temporally ordered routing algorithm in reactive and zone routing protocol in hybrid routing protocols (Gerla, 2005; Jayakumar & Chellappan, 2006; Shah *et al*., 2008; Gowrishankar *et al*., 2009; Ramakrishnan *et al*., 2010; Yazır e*t al*., 2010).

As there are many mobility models and protocols available, understanding each individually and in comparison with others is vital to enhance the existing model/ protocol or to develop a new one. Various surveys have been carried out on different sets of protocols to bring their merits and demerits over a scenario. Routing protocols are categorised based on their nature as location based protocols, basic routing protocols and security based protocols. Advantages and disadvantages of 10 different protocols have been analysed with parameters such as proactive/reactive, location based/identity and security (Mohandas *et al*., 2013). Performance of the protocols applied in the majority such as DSR, AODV and DSDV are analysed for user datagram protocol (UDP) and transmission control protocol (TCP) connections. The advantages and disadvantages of these protocols are compared with a few parameters such as route establishment and route maintenance (Karmel & Jayakumar, 2013). A survey on the nature inspired routing algorithms based on ant, bee and termite colonies have been compared on the basis of the most significant parameters that characterise state-of-the-art routing algorithms for MANETs (Jha *et al*., 2011). Performance analysis is done with respect to end-to-end delay, throughput and packet delivery ratio for varying node densities on proactive routing protocol DSDV and reactive routing protocol AODV, DSR. The mobility model on the basis of the metric for the protocols has been suggested (Rohankar *et al*., 2012).

A new AODV-efficient and dynamic probabilistic broadcasting approach has been proposed by Dembla & Chaba (2010), to solve the broadcast storm problem in AODV. This resulted in improved performance by reducing the communication overhead incurred during the route discovery process on AODV protocol. A similar kind of overhead reduction has been tried with a different strategy (Kumar *et al*., 2011). In this a trial has been made to get rid of the backtracking method during link failure. Hence the size of the routing table is also reduced by avoiding scrupulous entries. Each node maintains the information of the nodes within their range rather than all nodes.

The pheromone of an ant colony has been used as a base for routing in MANET (Hoolimath *et al*., 2012). Route request and reply are done with the additional information of a pheromone. Whenever a data packet is received, the routing information (pheromone) for its source is incremented by a constant to help retain the optimal path to exist for a longer time. The less optimal route is eliminated by removing the lower threshold over pheromone.

Features learned from animal behaviour

From the study of animal behaviour, it is very clear that communication is fast and effective mainly because of the initiator of communication. The responsibility of initiation is with the animal, who moves out of the group or who is in search for a mate or who knows or gets the knowledge of a dangerous situation. The observations are depicted in Table 1.

Table 1: Features learned from animal behaviour

Diffusion / reunion type	Animal type	Communication initiator	Reason	Learned feature
Re-orientation	Bird / bat / fish	Leader / informer	Initiates change in the plan	Who is responsible for causing change
Prey hunting / predator attack	Bird / bat / fish	Individual who identifies prey / predator	Others have no knowledge	Who is responsible for knowing the situation
Mate finding	Bird / bat	Individual interested in finding a mate	Individual need to find a mate	Who is interested
Mate finding	Fish	Fish ready to lay eggs	Need a mate who can produce sperms simultaneously for fertilization	Who is ready to find the availability of others

Utilisation of features learned from animals

Although a few studies have been done on routing based on animal behaviour, their perception has been totally towards path finding and not on path retention. Ant colony optimisation is a widely used animal behaviour used to find the link as to how the ant is following its neighbour by pheromone secretion. Path retention was not given much importance as path finding was done. Since it is well understood that a path cannot be permanent with respect to MANET due to its mobility, path retention is also equally important between source and destination. In order to do this, the knowledge of the node mobility must be incurred and also it must be communicated to the other nodes involved in the path. Who will be incurring the knowledge and who will be informing the others (initiator) is vital in MANET. With the existing protocols this may be found only after the reception of a periodical update packet, by the time the link will break and loss incurred. To avoid this issue an initiator must be found to inform the others before link failure or at least immediately after the node failure. The identification and making use of the initiator is the unique feature of this ACS algorithm. How it is derived from animal behaviour and used in ACS is illustrated in Table 2.

Table 2: Utilisation of features learned from animals to ACS

Issue in MANET	Reason for the issue	Why it remains unsolved	Feature learnt from animals	Utilisation of the feature in MANET	Outcome (in ACS)
Link failure	Node (A) in the path is away from the transmission range	Neighbour node (B) in the path does not know when 'A' will be away	Who is responsible for causing change	Only 'A' which moves knows that it is moving, so it must inform its neighbours	Use 'A' as initiator and send update packets (RERR)
Link failure	Node (C) is within the range but not available logically (battery, device failure)	Node 'C' is unable to inform others, but neighbour node (D) understands	Who knows the situation (e.g. animal who saw the predator)	Node 'D', after gaining this knowledge has to inform others to avoid cascading failures	Use 'D' as initiator and send update packets (RERR)

Step 1: At source, generate RREQ packet and send it to the neighbours in one hop distance.

Step 2: The intermediate nodes in one hop distance named 'intermediate node 1' will forward the RREQ to its neighbours in one hop from itself.

Step 3: At all other intermediate nodes named 'intermediate node n' may receive more than one RREQ.

- If sequence number of an already forwarded packet is received, simply drop the packet.
- If there is more than one packet on same sequence number, select a packet which has minimum hop count.
- If the packets are with different sequence numbers forward all the packets to its one hop nodes in case of nodes 2 to n-1 and to the destination in the case of node n.

Step 4: At destination generate an RREP packet for each sequence number and send it to the nodes from which the RREQ was received.

Step 5: At all the intermediate nodes who receives the RREP will reply to the nodes from which the RREQ was received.

Step 6: All the intermediate nodes in one hop distance which received the RREQ from the source will send RREP to the source.

Figure 1: Algorithm to set initial path between nodes

METHODS AND MATERIALS

The major problem identified in the maintenance of the path found between the two nodes, was to know the availability of the nodes involved in the path. In order to do this each node has to ensure their neighbour's availability and adjust their routing table with respect to proactive routing protocols. Periodically the nodes will send route update packets to their neighbours of one hop to get their availability. This will cascade to increase the consumption of battery power and traffic. The idea behind this work is to reverse this responsibility as in the animal kingdom in such a way that the node, which tends to move or knows that the next node is out of transmission range can inform its neighbours. Then the neighbours need to adjust their routing table only during this time and their neighbours in turn can repeat the same.

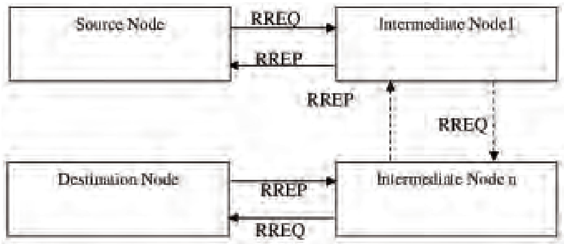

Figure 2: Initial path discovery in DSDV

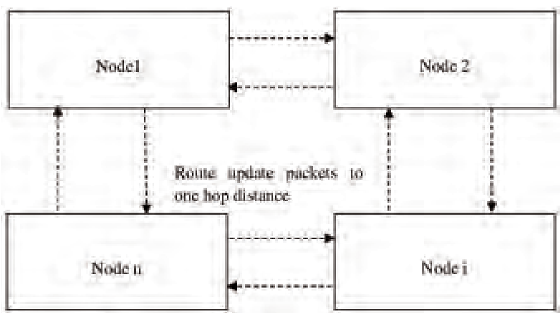

Figure 3: Path update through route update packets

```
procedure ACS
begin
//  initiator – self - during out of range with update packet through  RERR
        if initiator
        then
   generate RERR packet with victim id          // initiator is the victim
             send RERR                          // to nodes in one hop
        endif;
          // intermediate node on reception of RERR  packet
        if (single RERR received)
        then if  (Routing table entry has victim id)
                  then
                    update routing table
                    forward RERR to nodes in one hop distance
               else
                    forward to nodes in one hop distance
               endif
          else                                          // Multiple RERR received
              select MN = RERR(min(hopcount))
              if  (Table entry has MN)
              then
                  update MN in table
              endif;
        endif;
// initiator - any node knows that the neighbour node is not available
        if initiator
        then
             update routing table               // victim - identified neighbour
                 generate RERR packet with victim id
             send RERR                          // to nodes in one hop
        endif;
          // intermediate node on reception of RERR  packet
        if (single RERR received)
        then if  (Routing table entry has victim id)
              then
                 update routing table
                  forward to nodes in one hop distance
              else
                  forward to nodes in one hop distance
              endif
          else                                          // Multiple RERR received
              select MN = RERR(min(hopcount))
              if  (Table entry has MN)
              then
                  update MN in table
              endif;
        endif;
end procedure;
```

Figure 4: ACS algorithm for routing table update

Initially all the nodes will set their routing table by finding paths to different destinations as in the algorithm in Figure 1. Each source will be sending the route request packet (RREQ) to the neighbouring nodes with the source id and destination id along with a sequence number to avoid looping and to know the latest path. Each node, which receives the route request packet will update the request packet by adding its own id, hop count and then forward the packet to its neighbouring nodes. This will continue till the packet reaches the destination node. Once the destination receives the route request packet, it will send the route reply packet (RREP) to the node from which the route request packet was received. The same process continues till the source node. Subsequently the nodes will update their routing tables during route reply. Architecture of this path finding procedure of a regular DSDV protocol is shown in Figure 2.

Architecture and algorithm of the proposed work

During path retention, all the nodes should update their routing table by sending update requests to the neighbouring nodes periodically or rebuild a path while knowing the link break in the case of a normal DSDV protocol (Figure 3). Everything can be done in a predefined manner but not dynamically. The ACS does not need to update its routing table periodically, but dynamically update whenever it receives a route update packet from its neighbour. In order to acquire this facility the 'initiator' must take the initiative of sending the route update packets to the network when it is about to leave or get the knowledge of one leaving the transmission range. After the initiator generates the update packets with the victim id, it is forwarded to its neighbours in one hop distance. On reception of the update packets, the intermediate node will update its routing table by removing the victim id entry, hence the unreliable dependence and reference over the victim is removed. The same technique is followed to update the routing table of nodes in the entire topology. This is the unique feature of ACS algorithm and is depicted in Figure 4. Since the nodes need not send update packets periodically and update the table as in the original DSDV,

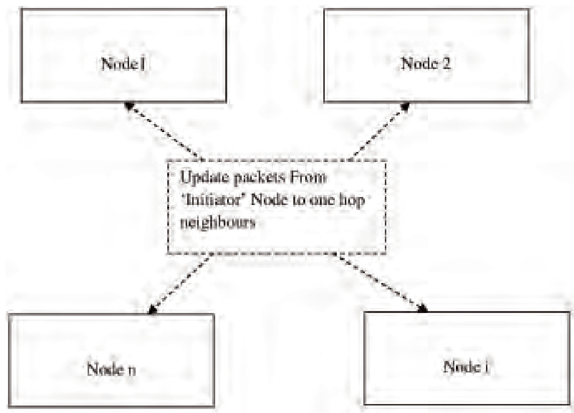

Figure 5: Route update packets from initiator to update neighbours table

the time, battery and memory overheads on path update will reasonably be reduced in ACS. Figure 5 shows the architecture of the proposed algorithm ACS during route update.

RESULTS AND DISCUSSION

Simulation environment

Performance evaluation of the ACS over DSDV protocol in this study for mobile ad-hoc networks was done using NS2. The simulation was done with 50 nodes communicating *via* the radio range of 250 m over the simulation area of 1000 × 1000 m. Total simulation time was 100 seconds. We have used the same constant bit rate (CBR) sources in both ACS and DSDV protocols with random walk and random way point mobility models. The packet size chosen was 512 bytes. The IEEE 802.11 protocol distributed coordination function (DCF) was used as the MAC layer protocol. The performance of routing protocols was evaluated by varying the mean speed. Identical scenarios in mobility and traffic are used and repeated 20 times for both protocols individually and the average was taken into graphs.

Performance evaluation

Metrics considered

- Packet loss percent (PLP) : ratio of the number of packets (equation 1) sent by the source node but not received at the destination node, i.e. dropped in between.

$$PLP = \frac{(Ps - Pr)}{Ps} \quad ...(1)$$

Ps - Number of packets sent
Pr - Number of packets received

- End-to-end delay (EED): Average time taken (equation 2) by the destination node to receive the packets.

$$EED = \frac{1}{n}\sum_{i=1}^{n}(td_i - ts_i) \quad ...(2)$$

ts_i - Time of packet sent from source
td - Time of packet received by the destination

- Control overhead (COH): Total number of routing control packets transmitted during transmission.

$$COH = \sum_{i=1}^{n} Pi \quad ...(3)$$

P_i - Control packets

In Figure 6 it is observed that packet loss percentage is gradually increasing as there is an increase in the speed

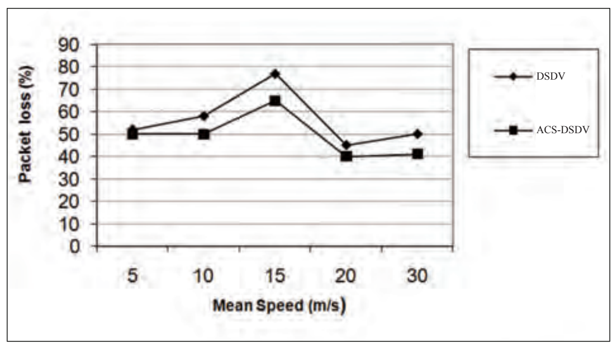

Figure 6: Packet loss percentage *vs* mean speed in random walk mobility model

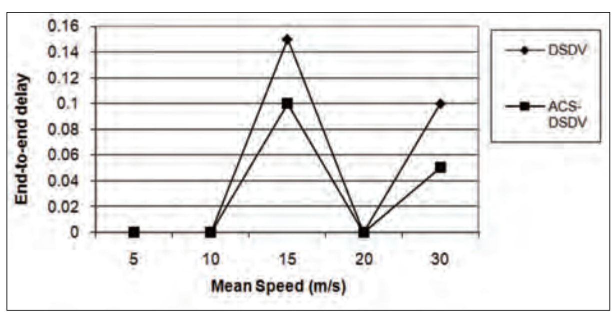

Figure 7: Average end - to - end delay *vs* mean speed in random walk mobility model

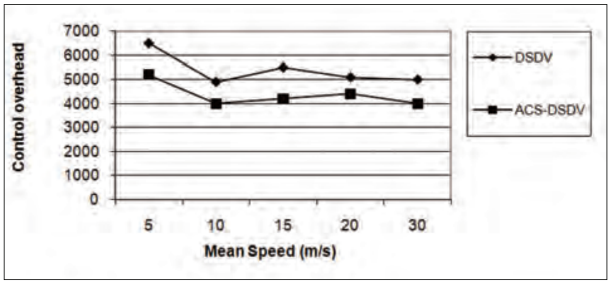

Figure 8: Control overhead *vs* mean speed in random walk mobility model

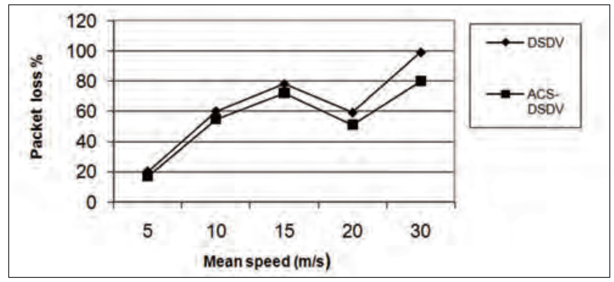

Figure 9: Packet loss percentage *vs* mean speed in random waypoint

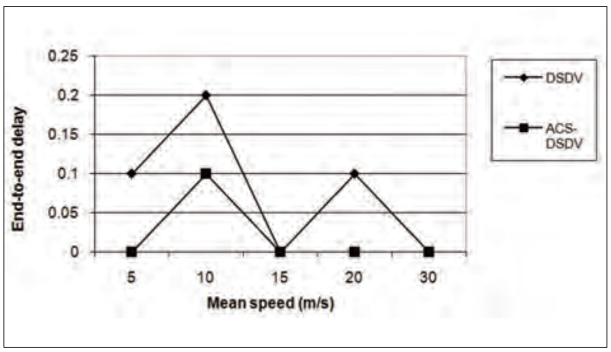

Figure 10: Average end-to-end delay *vs* mean speed in random waypoint

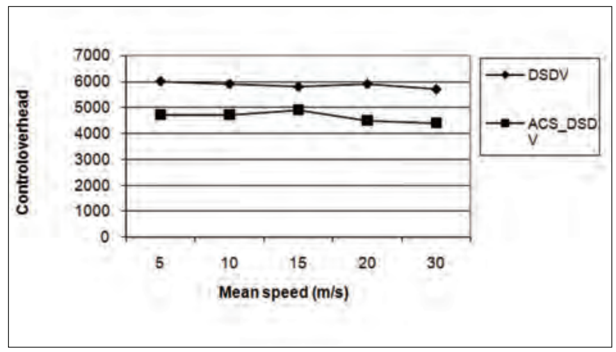

Figure 11: Control overhead *vs* mean speed in random waypoint mobility model

Table 3: Performance comparison of ACS and DSDV

Metric	Mobility model	Protocol	Result obtained	Remark
Packet loss percentage	Random waypoint	ACS	Loss is less than DSDV curve	Shows improvement
	Random walk	DSDV	Loss is more than ACS curve	Reduced performance
End-to-end delay	Random waypoint	ACS	Packet delivery is faster compared to DSDV	Shows improvement
	Random walk	DSDV	Takes more delay time than ACS	Reduced performance
Control overhead	Random waypoint	ACS	Overhead is less than DSDV	Shows improvement
	Random walk	DSDV	Increased overhead compared to ACS	Reduced performance

and peaks at 15 m/s. There is a change in the curve as it drops down at 20 m/s. Although both curves are looking similar at 5 m/s and are closer to each other at 20 m/s, the ACS enabled DSDV shows a significant improvement as it is always below the DSDV curve.

In Figure 7, the average delay seems very low and equal at 5,10 and 20 m/s for both DSDV and ACS. The delay is observed to be very high at 15 m/s for DSDV and for ACS it is reasonably less when compared to DSDV. Also it is observed that the delay in ACS is never higher than DSDV.

Figure 8 shows that the control overhead is high at a mean speed of 5 m/s and less at 10 m/s for both protocols. There is a fluctuation in the overhead as there is a change in the speed after 10 m/s. A significant improvement was observed in the control overhead as the speed increases in both protocols. A constant reduction in the control overhead curve of ACS over DSDV was also observed in all speeds.

The observation of packet loss in Figure 9 shows that the protocols show reduced performance as the speed increases from 5 - 15 m/s. The curve is getting better at 20 m/s and again the packet loss increases at 30 m/s. Although the curve is not showing improvement in packet loss in its entirety, a closer observation clearly explains the improvement of ACS over the DSDV protocol.

Although both protocols in Figure 10 start with different end-to-end delays at a lower speed of 5 m/s and vary much in the intermediate speed limits of 10 and 20 m/s, they are equal at 15 and 30 m/s. DSDV protocol has a fluctuating delay between different speed limits as the curve goes up and down. Interestingly, ACS is always better than DSDV and gets stabilized towards the higher speed limits.

From Figure 11 it is observed that the control overhead is not stable between different speeds in DSDV curve. Although the control overhead of ACS increases at 15 m/s, it slowly gets better towards higher speed limit. It is also obvious that the performance of ACS is better than DSDV in all speed limits as the overhead of DSDV is not similar to ACS.

In general the performance of the protocols is compared with the metrics considered above. The protocol, which earns less PLP, less EED and less COH is considered as better than the other. In consolidation from the above performance graphs it is proven that the proposed algorithm (ACS) is performing better when compared to DSDV. The results have been compared in Table 3.

Performance analysis

The results obtained from the simulation work were analysed by multiple regression analysis using equations 4, 5, 6 and 7 in order to investigate the similarity and variance between ACS and DSDV over the performance metrics considered (Gupta & Kapoor, 2008).

$$y = \sum_{i=1}^{p} (m_i x_i) + b \qquad ...(4)$$

$$m = \frac{n\sum(xy) - \sum x \sum y}{n\sum(x^2) - (\sum x)^2} \qquad ...(5)$$

$$b = \frac{\sum y - m\sum x}{n} \qquad ...(6)$$

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum(x^2) - (\sum x)^2 n][\sum(x^2) - (\sum x)^2]}} \qquad ...(7)$$

Table 4: Regression statistics of ACS and DSDV for random walk

Regression statistics	Metrics Packet loss %	End – end delay	Control overhead
Multiple R	0.993357	0.995305	0.934481
R square	0.986758	0.990632	0.873255
Adjusted R square	0.973515	0.981263	0.74651
Standard error	1.633098	0.006122	250.7297

Table 5: Regression coefficients of ACS and DSDV random walk

Coefficients	Metrics Packet loss %	End – end delay	Control overhead
Intercept	12.18102	0.006745	664.8791
X_1	- 0.25845	- 0.00062	- 2.03996
X_2	0.729684	0.663812	0.690326

Table 6: Regression statistics of ACS and DSDV for random waypoint

Regression statistics	Metrics Packet loss %	End – end delay	Control overhead
Multiple R	0.99641	0.816497	0.898952
R square	0.992833	0.666667	0.808114
Adjusted R square	0.985666	0.333333	0.616228
Standard error	2.91673	0.036515	120.7615

The study also helps to predict the ACS coordinates (Y) from the given mean speed (X1) and DSDV (X2) coordinates.

Tables 4, 5, 6 and 7 depict the primary factors obtained from the analysis done through data analysis tool - regression of MS Excel.

The regression equation to predict ACS from DSDV can be derived using equation (8) from the Tables 4, 5, 6 and 7.

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + \ldots \qquad ...(8)$$

Tables 5 and 7 determine the coefficients (ai) that yield the smallest residual sum of squares (SS), which is equivalent to the greatest correlation coefficient squared, R^2, for equation (8).

Table 7: Regression coefficients of ACS and DSDV for random waypoint

	Metrics		
Coefficients	Packet loss %	End – end delay	Control overhead
Intercept	1.536141	- 0.03333	16662.50
X_1	- 0.63909	0.000889	- 34.1667
X_2	1.007742	0.488889	- 1.95833

R square = (multiple R)^2 = R^2 = 1 - residual SS / total SS
= regress SS / total SS
Adjusted R square = 1 - (total df / residual df)(residual SS / total SS)
Standard error = (Residual MS)

Where, R is the correlation coefficient 'r' in equation (7) and df is the degrees of freedom.

In Tables 5 and 7 the values intercept, x_1 and x_2 are the coefficients a_0, a_1 and a_2 in equation (8).

Equations of Y obtained using equation (8) from Table 5 are:

Y for PLP = $(-0.25845)*X_1 + 0.729684*X_2 + 12.18102$

Y for EED = $(-0.00062)*X_1 + 0.663812*X_2 + 0.006745$

Y for COH = $(-2.03996)*X_1 + 0.690326*X_2 + 664.8791$

Equations of Y obtained using equation (8) from table 6 are:

Y for PLP = $(-0.63909)*X_1 + 1.007742*X_2 + 1.536141$

Y for EED = $0.000889*X_1 + 0.488889*X_2 - 0.03333$

Y for COH = $(-34.1667)*X_1 - 1.95833*X_2 + 16662.5$

CONCLUSION

Learning from animal behaviour is not new for human society. The learning outcome of the animal communication strategy helped to improve routing over the existing protocols in MANET environment. MANET requires an initiator node that has the knowledge of change in the structure and takes the responsibility of informing other nodes to avoid link failure. Identifying the initiator is done using animal behaviour and adopted in the proposed algorithm ACS. The ACS algorithm and DSDV are run separately using NS2 simulator. The results were compared with standard metrics such as PLP, EED and COH and shown in graphical form. In all the three metrics considered, ACS has less loss, delay and overhead and therefore can be declared as a better algorithm.

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