The Impacts of Dynamic Broadcast Schemes on the Performance of Routing Protocols in MANETs

Dimitrios Liarokapis
School of Engineering and Computing
Glasgow Caledonian University
Glasgow, UK
e-mail: Dimitrios.Liarokapis@gcu.ac.uk

Ali Shahrabi
School of Engineering and Computing
Glasgow Caledonian University
Glasgow, UK
e-mail: A.Shahrabi@gcu.ac.uk

***Abstract*—In this paper, a new implementation of AODV, called AODV-ProbA, is presented that substitutes SF with the Probability-based Adaptive (ProbA) broadcast algorithm. AODV-ProbA is compared against normal AODV and another proposed enhancement for AODV, called DP-AODV. An algorithmic comparison between AODV-ProbA and DP-AODV shows minor but critically important differences in the use of local density knowledge and adjustment of the probability threshold. The simulation results also confirm our hypothesis that AODV-ProbA performs considerably better than AODV and DP-AODV in highly mobile dense networks under moderate to heavy traffic load.**

Keywords-dynamic; adaptive; probability; broadcasting; MANETs

I. INTRODUCTION

Over the past few years many studies have been conducted to develop broadcast mechanisms to alleviate the effects of SF [1], [2]. The focus of the early works was on the schemes where the mobile nodes make the rebroadcast decision based on fixed and preconfigured thresholds. Despite the fact that these schemes have been shown to considerably improve the overall performance of the network, they have been found to highly depend on the combination of threshold selected, density and load. The degree of dependency is such that in certain network topologies even SF performs better than these schemes [3].

Adaptive schemes have consequently been proposed to alleviate these dependencies. In such schemes the threshold used for the broadcast operation changes according to the local density of the network, within the transmission range of the sender (number of one hop neighbors) or within an expanded neighborhood area (number of two hops neighbors). To determine the density of the network locally, most of these schemes either exchange HELLO packets [4], [5] or use a positioning system such as GPS [6]. These schemes either introduce more overhead traffic to the network or demand the existence of expensive, and in many cases not very reliable, positioning systems. There are also adaptive schemes that decide upon the local density of the network based on duplicate receptions of a packet for the duration of a random or fixed period of time [7], [8].

A wide variety of broadcasting algorithms are being proposed under different assumptions. However, the credibility of simulation results and conclusions made when the network is only under broadcast traffic is very questionable as such scenarios are highly unrealistic. This approach ignores the dynamic interactions between broadcasting algorithms and other components of networks. Hence, it is critical that when proposing a new algorithm, we evaluate it with accurate modelling of the underlying routing protocols and communication mechanisms. Clearly, after using such models a comprehensible understanding of the factors that affect the performance of a network emerges.

In this paper, we evaluate the performance of SF, ProbA [7] and DP [8] as broadcast mechanisms that take part in the route discovery process of the AODV routing protocol. In order to assess network performance, three performance metrics, namely packet delivery ratio, end to end delay and throughput, are used. This is attributed to the fact that the level of network performance visible to the end user is more important than that of internal network components.

The rest of this paper is organized as follows. Section 2 presents the related work for broadcasting in MANETs including a brief description of ProbA and DP. The algorithmic comparison of ProbA and DP is presented in Section 3. The results of extensive simulation study are presented in Section 4. Finally, Section 5 concludes this paper.

II. RELATED WORK

Over the past years some probability-based (PB) algorithms have been proposed for broadcasting in MANETs. Probability-based algorithms are those which decide upon relaying a broadcast message using a probability value. ProbA and DP are two probability-based (PB) algorithms which have been proposed recently.

A. Probability-based Adaptive (ProbA) Scheme

This approach introduces an extra step in the PB algorithm. According to PB, the receiving node applies the fixed probability threshold for the broadcast decision exactly after the packet is received. In ProbA, the mobile node falls into a listening mode for a random number of time slots upon reception of a new broadcast message.

ProbA takes advantage of this listening period and calculates the number of duplicate packets received, using a simple counter which is initialized to a value of 1 when a broadcast packet is received for the first time. The number of identical packets arriving at the mobile node is closely connected to the number of neighboring nodes. Each time the value of the counter increases, the probability threshold is tuned according to a pattern that is introduced administratively. This pattern is a scaled “if” statement, where the probability threshold changes its value depending on the current counter value. The number of possible values

 ISBN: 978-1-61208-140-3

```
Algorithm: ProbA
Input: broadcast message (msg)
Output: decides whether to rebroadcast msg or not

if ( msg is heard for the first time ) {
  count = 1;
  Generate a random number rand between 1 and 100;
  while (wait for a random number of slots){
    if (msg is heard again)
      count++;}
  if (count < c1)
    P = P1;
  else if (count < c2)
      P = P2;
    else if (…
    … … …
  else if (count > cn)
    P = Pn;
  if (P > rand)
    exit;
  else { submit msg for transmission;
          exit;}}
```

Fig. 1: ProbA algorithm.

for the probability threshold is a parameter that is set by default but needs to follow an exponential and not a linear trend [9]. The value of the probability threshold could change multiple times during the listening period and every time a duplicate broadcast packet is received. The details of the ProbA algorithm are presented in Fig. 1 where P is the probability threshold, *count* is the counter described above, P_1, P_2, …, P_n are the pre-determined probability threshold values and c_1, c_2, …, c_n are the pre-determined counter values.

ProbA's primary goal is not to accurately calculate the number of neighboring nodes, but to decide upon the active density level of the network locally inside the transmission radius. This feature gives an extra advantage to ProbA in comparison to other adaptive schemes. An algorithm which is based on HELLO packets or a GPS system cannot properly estimate the number of active nodes retransmitting a broadcast message. For instance, grey node (GN) in Fig. 2 calculates the exact number of nodes inside the transmission radius. Either using GPS or HELLO packets, the end result of the calculation will be very close to 12, the total of all white nodes (WN) and black nodes (BN). As a result, GN will decide that the network is very dense locally and tune the probability threshold to be low (for example 10%), in order to avoid rebroadcasting that may cause collisions and contention. As the threshold is now very low, it is very likely that GN will not rebroadcast. Thus, none of the WNs will receive the broadcast packet.

In ProbA, GN will wait for a random period of time counting duplicate packets, Fig. 3. As GN has received a message once the counter will be set to 1 requiring a very high threshold value (for example 90%). It is highly possible at this point, as the threshold is very high, that GN will rebroadcast the packet and all WNs will receive it.

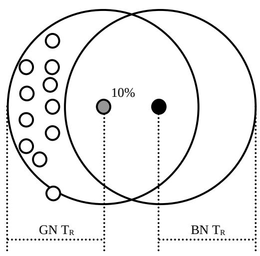

Fig. 2: HELLO-GPS

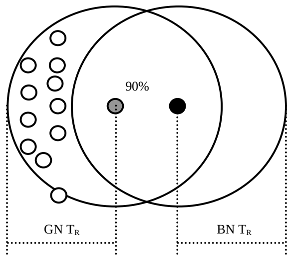

Fig. 3: ProbA

B. Dynamic Probabilistic (DP) Broadcasting

DP also uses a packet counter in order to estimate the density of the network locally. A counter is maintained in every node for every broadcast packet received. The counter increases by 1 every time a duplicate packet is received. A high counter value implies high local density and, on the contrary, a low counter value represents a low level of local density. The probability threshold is increased in case that the counter is very low and decreased if it is high.

The decision of a node to increase or decrease the probability threshold and consequently to rebroadcast the packet or not has an effect on the neighboring nodes counter, as a rebroadcast will in turn increase their counters. According to the [8], "this kind of adaptation causes a dynamic equilibrium between rebroadcast probabilities and packet counter values among neighboring nodes". This equilibrium state should lead to optimal results, although it is hard to reach that state as the mobile nodes may be constantly moving. For that reason, the probability threshold needs to be adjusted as quickly as possible. In addition, according to DP drastic changes in the probability threshold should be avoided.

DP dictates that a node should rebroadcast a packet depending on the current probability P if the packet is received for the first N_C times, where N_C is the threshold value to indicate whether enough duplicate packets were received or not. The probability P is decreased by a small constant d when an additional copy beyond N_C of an existing packet is received. The probability P is increased by another small constant d_1 if a node has not heard anything within a time interval t. An upper P_u and a lower P_l bounds are also set. The algorithm is presented in Fig. 4.

Setting the value of t and the initial value of P is critical. If t is set too low, the counter may be checked too often and the packet counter may remain low. In this case, the probability value could remain the same. If t is set too high the counter may be checked too less and the packet counter may exceed the threshold often and the probability could be set too low.

The value of $N_{neighbour}$ is calculated using the formula:

$$N_{\text{neighbour}} = (N-1)\frac{\pi R^2}{A}. \quad (1)$$

The initial value of P is set as follows.

Algorithm: DP
Input: broadcast message (*msg*)
Output: decides whether to rebroadcast *msg* or not

```
if (msg is received){
  if (msg is in the received message list)
    if (count > NC){
      P = P – d;
      if (P < Pl)
        P = Pl;
    }
    count = count + 1;
else {
  count = 1;
  Add msg ID to the received packet list with an expiration time;
Submit msg for transmission with probability P;
#########################################
for (every time interval t)
  if (no msg is received within t)
    if (count < NC){
      P = P + d1;
      if (P > Pu)
        P = Pu;
      Remove msg ID from received message list;}
```

Fig. 4: DP algorithm.

$$P = \begin{cases} 1, & \text{where } \dfrac{6}{N_{\text{neighbour}}} \geq 1 \\ \dfrac{6}{N_{\text{neighbour}}}, & \text{where } \dfrac{6}{N_{\text{neighbour}}} < 1 \\ 0, & \text{where } \dfrac{6}{N_{\text{neighbour}}} \leq 0 \end{cases} \quad . \tag{2}$$

III. PROBA VS DP

The core of both ProbA and DP algorithms is to adaptively make decision to rebroadcast a packet or not depending on the local density of the network. A node starts a timer to enter a listening (or learning) mode upon reception of a new broadcast packet. During listening period, duplicate packets are counted. A high value reflects high number of active neighbouring nodes requiring a lower value for probability threshold. On the contrary, if the counter value is low, the probability threshold value needs to have a high value as a rebroadcast will provide a significantly large extra coverage area and thus the broadcast operation will most likely not die out. It should be remembered that the local density of the network is not calculated accurately. The counter value is just an indication of the number of active neighbouring nodes. This is not an algorithmic weakness as the counter value is proportional to the node density in the surrounding area for a given rebroadcast probability distribution among neighbouring nodes.

Despite the fact that both algorithms are based on the same logic of implementing adaptivity, they differ in two critical points; how the listening period is accommodated inside the broadcast algorithm and what is followed when adjusting the probability threshold.

A. Listening Period

According to the DP algorithm, a node does not wait for the timer to expire before making the rebroadcast decision. It immediately decides whether to rebroadcast or not. The timer is used to accumulate knowledge for future decisions. The counter increases when a duplicate packet is received and in turn the probability threshold is decreased. If nothing is heard during the listening period the counter is constantly set to 1 and the probability threshold is increased. Whereas, the ProbA algorithm dictates that the node can only decide upon the rebroadcast of the packet after the timer has expired, thus it makes its decision based on freshly obtained knowledge upon the local density of the network. DP would perform poorly when the network topology changes fast, as the node would base its decision on some stale knowledge. This laziness may lead to poor performance in highly mobile networks.

DP may look faster than other timer-based algorithms, as pointed out in [8]. However, this could only be true if the timer value is greater than 5-10% of the total end to end delay of the entire process. For example, a waiting time of 30ms does not have a significant effect on a process that could last 300ms or even longer in case of high traffic load in the network where delay can exceed the value of 1sec. Furthermore, a small waiting time could also aid to avoid further collisions and consequently a rather lengthy back-off process.

B. Probability Threshold Adjustment

The increase or decrease of the probability threshold is closely related to the potential additional coverage area that could be achieved when the broadcast packet is transmitted. If a large extra area is predicted to be covered by rebroadcasting of a packet, the probability threshold should be set to a high value. That is the case when the counter value is low. On the contrary, if the predicted coverage area is small, the probability threshold should be adjusted to a low value. This is also the case when the counter value is high. It is obvious that counter value, probability threshold and extra coverage area greatly affect one another in that order.

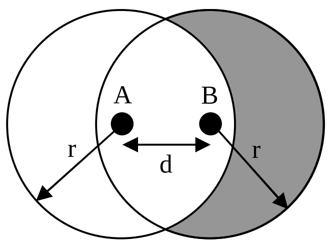

Fig. 5: Extra area analysis

The DP algorithm uses a linear pattern for the adjustment of the probability threshold. For every increase of the counter value, the probability threshold is decreased by a small constant [8]. Furthermore, for every time interval that there are no duplicate broadcast packets received, the probability increases by another small constant. The ProbA algorithm makes use of a scaled *if* statement for the adjustment of the probability [7]. This should lead to an exponential decrease of the probability depending on the counter value. An example of the scaled *if* statement is as follows:

if(*count* = 1) *P* = 90%;
else if(*count* < 4) *P* = 50%;
else *P* = 10%;

In order to conclude which of the two patterns is more suitable, we need to take into consideration the redundant rebroadcast analysis performed in [9]. Consider the scenario in Fig. 5. Node A sends a broadcast packet and node B decides to rebroadcast it. Let S_A and S_B denote the circle areas covered by the transmission ranges of nodes A and B respectively. The gray area represents the additional area that will be covered by B's rebroadcast named S_{B-A}. We can derive that:

$$\left|S_{B-A}\right| = \pi r^2 - INTC(d)\,, \tag{3}$$

where *INCT(d)* is the intersection area of the two circles centered at two points distanced by *d*.

$$INTC(d) = 4\int_{d/2}^{r} \sqrt{r^2 - x^2}\,dx\,. \tag{4}$$

The extra coverage area gets the maximum value when *r* = *d* and is equal to:

$$\pi r^2 - INTC(r) = r^2\left(\frac{\pi}{3} + \frac{\sqrt{3}}{2}\right) \approx 0.61\pi r^2\,. \tag{5}$$

Thus, B's rebroadcast can cover an extra area of 61% of the area covered by the previous transmission. The average extra coverage area can be obtained by integrating the above value over the circle of radius *x* centered at A for *x* in [0, *r*]:

$$\int_0^r \frac{2\pi x \cdot \left[\pi r^2 - INTC(x)\right]}{\pi r^2}\,dx \approx 0.41\pi r^2\,. \tag{6}$$

A rebroadcast can cover an additional of 41% area in

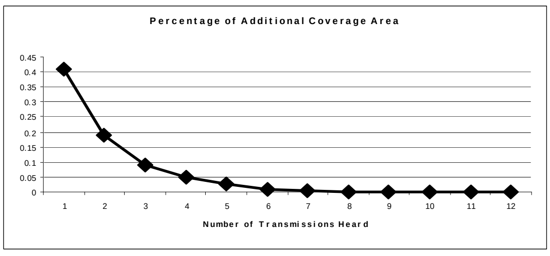

Fig. 6: Analysis of Redundancy

average. Following the same pattern, the extra area covered can be calculated depending on the number of transmissions heard for the broadcast packet. The result is shown in the graph of Fig. 6.

This analysis confirms ProbA's hypothesis that the probability threshold adjustment should follow an exponential and not a linear decrease pattern proving the superiority of ProbA over DP.

IV. PERFORMANCE ANALYSIS

In this section, we present the simulation results of our performance comparison study that will confirm the findings of the algorithmic comparison performed in the previous section. The algorithms of normal AODV with AODV-ProbA and DP-AODV are compared. The performance metrics for comparison include the packet delivery ratio (PDR), end to end delay, and throughput.

A. Simulation Setup

The simulator used for the experiments is NS-2. All experiments are grouped into 3 different categories depending on node density, traffic load (number of connections) and mobility. For the first group of scenarios node density increases from 20 nodes up to 200 nodes with a constant step of 20. The second group includes the results against traffic load starting from 20 TCP connections and reaches the maximum of 60 connections, again with a constant increase step of 10 connections. The last group evaluates the performance of the three algorithms against mobility. The starting point for the node speed is 10m/s and increases by 5m/s until it reaches the maximum value of 30m/s.

All nodes are placed randomly within a network topology of 1000x1000 square meters. Transmission range for all nodes is set to 250m and channel capacity is 2Mbps. Each simulation run is executed for 800sec of simulation time. Nodes move inside the network with a maximum speed of 20m/sec for the first two groups and 0 pause time for all. Node movement is generated using the setdest command provided by NS-2, following the random waypoint model. Every scenario is run 3 times with different random movement of nodes, in order to avoid any extremes that could compromise the reliability of our results. Final results are calculated as the average of the 3 repetitions. Default AODV parameters are used for all protocols, as our implementations only dealt with the broadcast mechanism used. The type of traffic used in our experiments is Constant Bit Rate (CBR). The number of connections per scenario was kept the same with a value of 50 connections for the first and third group of experiments. Packet generation rate is set to 1.0 packet per second. Data payload is 512 bytes.

AODV-ProbA uses 3 different probability thresholds depending again on the density of the network locally. Values for the probability thresholds used are, 10% for counter value of 1, 50% for counter values of 2 and 3 and 90% for counter values of 4 and higher. Probabilities are set following an exponential pattern as described in III.B. The algorithm of DP-AODV requires the set of 5 additional parameters. They are summarized in the table below:

TABLE I. DP-AODV PARAMETERS

Probability Decrease Constant *d*	1%
Probability Increase Constant d_1	2%
Time interval *t*	35msec
Upper Probability Bound	90%
Lower Probability Bound	10%

The initial probability threshold *P* is calculated using the formula presented is Section II.B. The justification for the values of *d* and d_1 is that the authors of DP argue in favor of non-drastic changes in the probability. Low values of 1% and 2% are chosen respectively. The value of d_1 is double the value of *d* in order to reach an equilibrium state. The probability *P* decreases more times in average as in our dense scenarios it is more likely for a node to receive the broadcast packet more than once during the simulation time. For reasons of fairness the time interval *t* for DP is set to 35msec. That is the average listening time for AODV-ProbA as well. Upper and lower probability bounds are set to the same values for both algorithms.

The following performance parameters are considered for our simulation experiments. It is noted that all metrics are concerned with both TCP and AODV traffic.

Packet Delivery Ratio (PDR) – The percentage of successful packet deliveries throughout the simulation time.

End to End Delay – The amount of time elapsed from the time a packet was originated from the source node until the time it as successfully delivered to the destination node.

Throughput – The average rate of successful data delivery in the network measured in kbps.

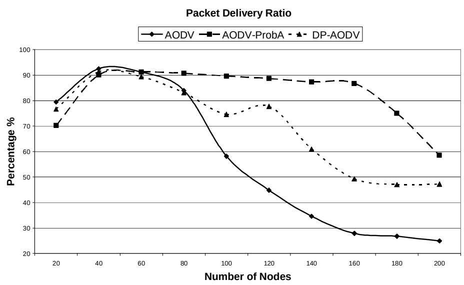

Fig. 7: PDR vs Density

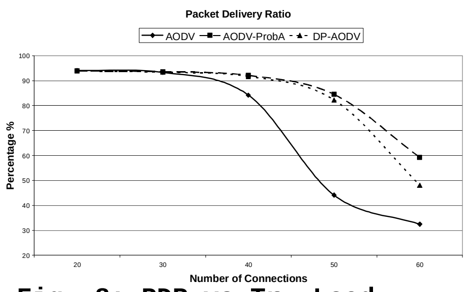

Fig. 8: PDR vs Tr. Load

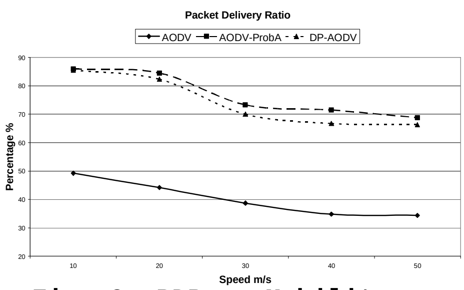

Fig. 9: PDR vs Mobility

B. Packet Delivery Ratio

A mobile node will miss a packet if all of its neighbors decide to suppress rebroadcast in case of an AODV packet or if there is a collision and the TCP packet never reaches its destination.

Fig. 7 shows the packet delivery ratio for a network against node density. All three algorithms perform in a similar way for sparse topologies of up to 60 nodes. For medium and high node density topologies, AODV-ProbA performs better than both AODV and DP-AODv. Fig. 8 shows the PDR percentage for a network against traffic load. Once again, for low traffic density of 20 and 30 connections, all algorithms produce the same results. In case of more connections, AODV-ProbA and DP-AODV perform better than normal AODV, with the latter been slightly outperformed. The PDR level of a network when node speed is increased is presented in Fig. 9. AODV-ProbA produces higher PDR for all average node speeds. Normal AODV performs poorly reaching down to 35% of PDR.

C. End to End Delay

In general, the metric of end to end delay is found to produce very similar trends with the results for PDR or reachability. Especially in scenarios with high levels of node and traffic load densities, back-off and medium detection mechanisms may delay the transmission of packets in addition to the high probability of the packet never reaching its destination.

As shown in Fig. 10, when AODV-ProbA is used, a packet travels from source to destination with high speed. The performance of DP-AODV is average when delay is measured and normal AODV produces unacceptable delay for medium and high node density networks. Fig. 11 shows the end to end delay for a network against traffic load. Both DP-AODV and AODV-ProbA perform better than normal AODV with the latter producing slightly lower average delay for all scenarios. End to end delay against mobility is presented in Fig. 12. Normal AODV with simple flooding causes delay to be on average 150% higher than the other two algorithms. Once again, AODV-ProbA slightly outperforms the Dynamic Probabilistic algorithm.

D. Throughput

Throughput is an important metric that represents a network's ability to transmit data. It is a very popular metric in QoS performance comparison studies in MANETs and is defined as the number of bits or kbits transmitted per time unit.

In Fig. 13 we compare the network throughput for different node densities. Normal AODV is outperformed for medium and high density levels. Despite the fact that performance for DP-AODV is slightly higher for sparse and average node density networks when compared against AODV-ProbA, when the network becomes extremely dense

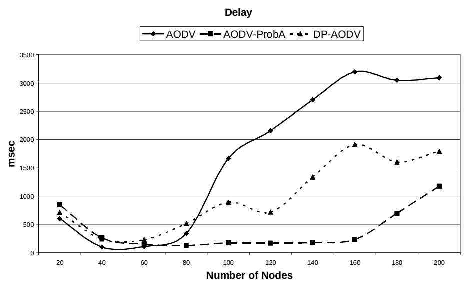

Fig. 10: Delay vs Density

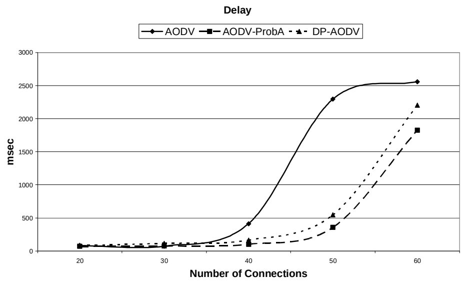

Fig. 11: Delay vs Tr. Load

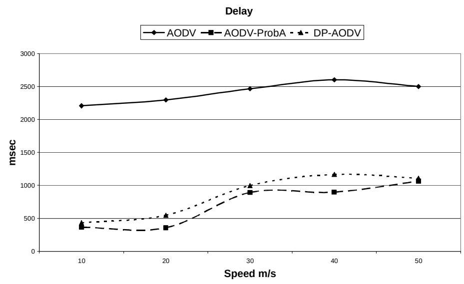

Fig. 12: Delay vs Mobility

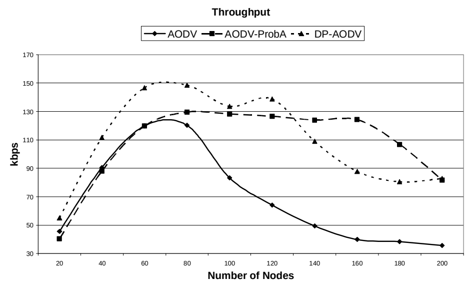

Fig. 13: Throughput vs Density

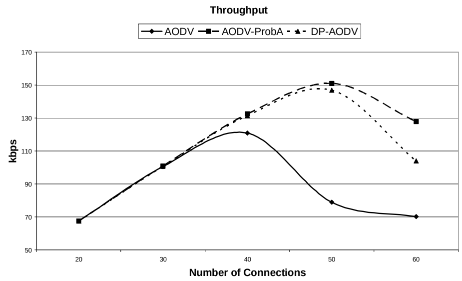

Fig. 14: Throughput vs Tr. Load

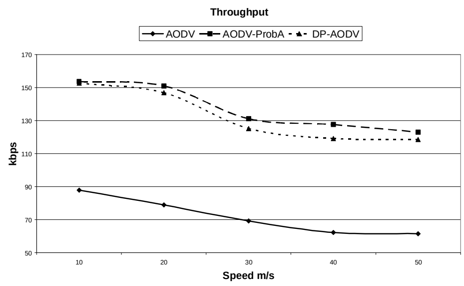

Fig. 15: Throughput vs Mobility

its performance rapidly decreases. The performance of a network in terms of throughput when different traffic loads are configured is shown in Fig. 14. All algorithms perform almost identical for 20, 30 and 40 connections. When the number of connections increases, throughput for normal AODV begins to decrease sharply. AODV-ProbA performs better than DP-AODV for very high traffic loads once again. Fig. 15 confirms the superiority of AODV-ProbA for scenarios with different node speeds, as it constantly produces higher throughput than AODV and DP-AODV.

V. CONCLUSION

In this paper, a comparison between the effects of two probabilistic adaptive schemes, ProbA and DP in AODV routing protocol has been presented. Two key differences between these two algorithms have been highlighted; the role of the listening period as part of the adaptivity mechanism and the way this is implemented in addition to the different mathematical pattern followed when adjusting the probability threshold. The result of this comparison has led us to the fact that ProbA should outperform DP in dense networks with highly mobile nodes. The experimental results presented in this work have confirmed the superiority of ProbA against DP in almost all simulation scenarios used in terms of packet delivery ratio, end to end delay, and throughput under various network sizes and traffic loads as well as different node speeds.

REFERENCES

[1] S. Leng, L. Zhang, L. W. Yu, and C. H. Tan, "An efficient broadcast relay scheme for MANETs," *Com. Com.* 28, 5, pp. 567-476, 2005.

[2] R. Purtoosi, H. Taheri, A. Mohammadi and F. Foroozan, "Improving broadcast performance by traffic isolation in wireless ad hoc networks," Res. Art. *Int. J. Com. Syst.* 19, 9, pp. 1029-1043, 2006.

[3] B. Williams, and T. Camp, "Comparison of broadcast techniques for mobile ad hoc networks," In *Proceedings of Mobile Ad Hoc Networking and Computing*, MOBIHOC, pp. 194-205, 2002.

[4] M. D. Colagrosso, "Intelligent Broadcasting in Mobile Ad Hoc Networks: Three Classes of Adaptive Protocols," In *Proceedings of EURASIP*, pp. 25-25, 2007.

[5] Y. Tseng, S. Ni, and E. Shih, "Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad Hoc Network," In *IEEE Transactions on Computers*, pp. 545-557, 2003.

[6] D. Young-Ching, S. Ching-Chi, and L. Ferng-Ching, "An Adaptive Medium Access Control Protocol for Reliable Broadcast and Unicast in Ad Hoc Networks," In *Proceedings of IEICE – Tran. on Inf. & Sys*, pp. 527-535, 2006.

[7] D. Liarokapis and A. Shahrabi, "A probability-based adaptive scheme for broadcasting in MANETs," In *Proceedings of the 6th international Conference on Mobile Technology, Application & Systems, ACM Mobility*, Nice, France, 2009.

[8] Q. Zhang and D. P. Agrawal, "Dynamic probabilistic broadcasting in MANETs," In *J. Par. Distrib. Comput*. 65, 2, pp. 220-233, Feb. 2005.

[9] S. Ni, Y. Tseng, Y. Chen and J. Sheu, "The broadcast storm problem in a mobile ad hoc network," In *Proceedings of the 5th Annual ACM/IEEE int. Conf. on Mobile Comp. and Networking*, MobiCom '99, pp. 151-162, Seattle, Washington, United States, 1999.