Computer Networks xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Impact of noise and interference on probabilistic broadcast schemes in mobile ad-hoc networks

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A R T I C L E   I N F O

Article history:
Received 14 August 2014
Revised 9 June 2015
Accepted 23 June 2015
Available online xxx

Keywords:
Mobile ad-hoc networks
Routing protocols
Pure flooding
Route discovery
Broadcasting
Performance analysis
Interference
SINR model
AODV

A B S T R A C T

Broadcasting is a vital part of on-demand routing protocols to discover new routes in mobile ad-hoc networks (MANET). Pure flooding is the earliest and still widely used mechanism of broadcasting for route discovery in on-demand routing protocol. In pure flooding, a source node broadcasts a route request to its neighbors. These neighbors then rebroadcast the received route request to their neighbors until the route request arrives at the destination node. Pure flooding may generate excessive redundant traffic leading to increased contention and collisions deteriorating the performance. To limit the redundant traffic, a number of probabilistic broadcast schemes have been proposed in the literature. However, the performance of those probabilistic broadcasting schemes is questionable under real life MANETs which are noisy in nature. Environmental factors like thermal noise and co-channel interference may have adverse effects on the system performance. This paper investigates the effects of thermal noise and co-channel interference on the performance of probabilistic schemes employed in the route discovery mechanism in MANETs. Based on extensive ns-2 simulations, this paper discovers that, contrary to the findings of previous studies, these schemes do not outperform pure flooding scheme when thermal noise and co-channel interference are taken into account.

1. Introduction

A mobile ad-hoc network (MANET) consists of a set of mobile nodes that can connect to each other over multi-hop wireless links on ad-hoc basis. These networks are self-organizing, self-configuring as well as self-healing without requiring any infrastructure or central administration [1-4]. These properties make a MANET an excellent candidate for a number of applications ranging from communication in battle fields to rescue operations in disaster areas.

MANET nodes can arbitrarily be located within an area and are free to move. The movement of MANET nodes changes the network topology dynamically. MANET nodes adapt to the changing topology by discovering new neighbors and establishing new routes to destinations [5].

Due to the limited transmission range, a node may not communicate directly with a distant node and may have to rely on its neighboring nodes to relay the message along the route to the final destination node. Therefore, each node acts not only as a host node but also as a relay node to extend the reachability of other nodes. When a node needs to send data to a remote node, first, it finds out a set of relay nodes between itself and the remote node. The process of finding the optimal set of relay nodes between the source node and the destination node is called routing. Node mobility, limited battery power and the error-prone nature of wireless links are the main challenges in designing an efficient routing protocol in MANETs.

A number of routing protocols have been proposed in the literature [6]. These protocols generally fall into three categories namely table-driven (proactive), on-demand (reactive) and hybrid routing protocols. Table-driven routing protocols

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http://dx.doi.org/10.1016/j.comnet.2015.06.013
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aim to maintain routes to all possible destinations in the network at all times. Examples of table-driven routing protocols include OLSR (Optimized Link State Routing) [7] and DSDV (Destination-Sequenced Distance-Vector) routing [8]. In contrast to table-driven approach, on-demand routing protocols, e.g., AODV (Ad-hoc On-demand Distance Vector) routing [9], DSR (Dynamic Source Routing) [6], and ABR (Associativity-Based Routing) [10], discover a route only when it is needed. Hybrid routing protocols, e.g., ZRP (Zone Routing Protocol) [11] and CEDAR (Core-Extraction Distributed Ad-hoc Routing) [12] combine the features of both proactive and reactive routing protocols.

In on-demand routing protocols, the routing process consists of two phases namely route-discovery and route-maintenance. These protocols rely on broadcasting for route discovery. For example, in case of AODV routing protocol, a source node that needs to send data to a destination node triggers route discovery mechanism by broadcasting a special control packet called Route Request (RREQ) to its neighbors who then rebroadcast the RREQ packet to their neighbors. The process continues until the RREQ packet arrives at the destination node. The destination node sends a control packet called Route Reply (RREP) that follows the path of RREQ in reverse direction and informs the source node that a route has been established. Since every node on receiving the RREQ for the first time rebroadcasts it, it requires N-2 rebroadcasts in a network of N nodes assuming the destination is reachable. This kind of broadcasting is called pure flooding and is depicted briefly in Fig. 1 while details can be found in [13].

Pure flooding often results in substantial redundant transmissions because a node may receive the same packet from multiple other nodes. This phenomenon, commonly known as the broadcast storm problem (BSP) [14], triggers frequent contention and packet collisions leading to increased communication overhead and serious performance complications in densely populated networks. The broadcast storm problem equally affects the route maintenance phase during which routes are refreshed by triggering new route discovery requests to replace the broken routes. To elevate the damaging impact of pure flooding, a number of improved broadcasting schemes have been proposed in the literature [14-16]. These techniques generally fall in two categories namely deterministic and probabilistic broadcasting. Deterministic schemes (e.g., MPR [17] and Self Pruning Scheme [18]) exploit network information to make more informed decisions. However, these schemes carry extra overhead to exchange location and neighborhood information among nodes. On the other hand, the probabilistic schemes, e.g., fixed-probabilistic [19], distance-based [20], counter-based [21] and location-based [14] schemes, take a local decision to broadcast or not to broadcast a message according to a predetermined probability. All these schemes try to minimize the number of rebroadcasted RREQ packets. In fixed-probabilistic scheme, a node receiving the RREQ packet rebroadcasts it with a fixed probability. In case of distance-based scheme, a node receiving the RREQ packets decides to rebroadcast by considering its distance from the sending node.

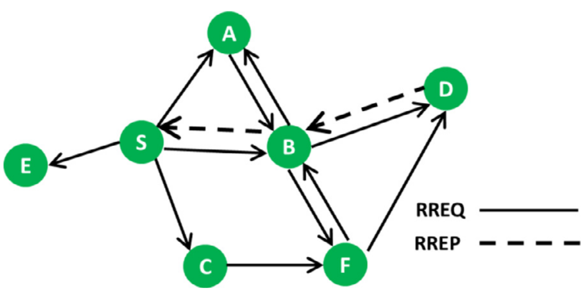

Fig. 1. Route discovery mechanism in AODV.

Real life MANETs are noisy and the communication is not error free. A number of channel impairments like noise, co-channel interference, signal attenuation, fading and user mobility affect the transmission. Previous studies have shown that routing protocols based on probabilistic broadcast schemes outperform the traditional pure flooding based routing protocols [14,22]. However, the results of those studies can be challenged for real MANETs. It is because those studies either ignored the noise and the interference at all [16,23] or they used a simplified model by translating the effects of noise and interference into a simple packet loss probability [24].

This paper investigates the effects of thermal noise and co-channel interference on the performance of probabilistic schemes by using realistic models of thermal noise and co-channel interference at physical and MAC layers. The investigations have been carried out for the fixed-probabilistic [19] and the distance-based [20] broadcast schemes. The performance is evaluated by considering routing overhead, application layer throughput, end-to-end delay and energy consumption. Through extensive ns-2 simulations and analysis of the simulation results, this paper reveals that, in contrast to the previous studies, the fixed-probabilistic and the distance-based broadcasting schemes do not show promising results when realistic thermal noise and co-channel interference at the physical and the MAC layers are taken into account. The rest of the paper is organized as follows. Section 2 highlights the related work. Section 3 presents the simulation setup, performance evaluation and discussion of results followed by conclusion in Section 4.

2. Related work

Cartigny and Simplot [26] proposed a probabilistic scheme where the retransmission probability is calculated from the number of neighboring nodes which are considering rebroadcasting. This work showed that a fixed parameter could be derived to enhance the reachability and demonstrated a substantial reduction in broadcast traffic yielding encouraging results. However, this work did not consider the effects of interference and thermal noise.

Zhang and Agrawal [22] suggested a probabilistic scheme that dynamically modifies the rebroadcasting probability based on the node distribution and the node movement by considering local information but without needing any distance measurements or exact location determination devices. Their results showed an improvement in performance when compared to both pure flooding and static probabilistic schemes. However, the effects of noise and interference were ignored. The same authors (in another work [27]) suggested

Please cite this article as: H.Y. Adarbah et al., Impact of noise and interference on probabilistic broadcast schemes in mobile ad-hoc networks, Computer Networks (2015), http://dx.doi.org/10.1016/j.comnet.2015.06.013

a leveled probabilistic routing scheme for MANETs. In this scheme, mobile hosts are divided into four groups and different rebroadcast probabilities are assigned to each group. The results showed gains in throughput.

Al-Bahadili and Sabri [24] proposed a probabilistic algorithm for route discovery based on the noise-level. However, this work used a model to estimate interference and noise values rather than measuring them at lower layers and passing it to the network layer.

Ruiz and Bouvery [23] proposed a cross layer design for enhancing the distance based broadcasting protocol in terms of energy consumption. They enhanced it by minimizing the transmission power of candidate node uses for the broadcasting process in order to reduce the number of collisions and save energy. Their results have shown that there was reduction in the number of collisions in the network and energy consumption. The gain increased with increase of network density. However, this work did not consider the effects of interference and thermal noise.

To the best of the authors' knowledge, no previous work on probabilistic route discovery mechanism has considered the effect of physical layer parameter such as thermal noise and co-channel interference. To remark conclusively about any probabilistic route discovery scheme if it is recommended approach or not for on-demand routing protocol in real life MANETs, the effect of interference and thermal noise has to be taken into account. This paper fills this gap and studies the effects of interference and thermal noise on the performance of a probabilistic route discovery scheme. In this paper, the signal strength, noise level and interference are measured at the physical and MAC layer and the resulting signal to interference plus noise ratio (SINR) is used to determine the successful reception of packets. SINR is a common way to represent a wireless channel and has been extensively used to measure the performance of wireless links [28]. Abrate et al. [29] presented a novel model to show the relationship of Packet Error Rate (PER) and SINR for different packet length.

Takai et al. [30] studied the role of physical layer modeling in evaluating the performance for higher layer protocols and their results revealed that the physical layer modeling is important even though the higher layer protocols do not interact with the physical layer directly.

Alnajjar and Chen [31] stated a cross-layer mechanism wherein the routing protocols adapt to the current Signal to Noise Ratio (SNR). This approach was implemented in DSR protocol and was shown to enhance the performance.

Linfoot et al. [32] studied the effects of physical and virtual carrier sensing on the AODV routing protocol. This work showed that the route discovery mechanism is affected by the interference and carrier sensing range and a suitable carrier sensing threshold is crucial for performance gains in noisy MANETs with high node density.

3. Performance evaluation of probabilistic broadcast

This section studies the impact of thermal noise and co-channel interference on the performance of the fixed-probabilistic [19] and the distance-based [20] broadcasting schemes employed in the route discovery process of AODV routing protocol in MANETs. The performance has been evaluated using four metrics namely routing overhead, throughput, end-to-end delay and energy consumption. The performance evaluation has been carried out both with and without taking the thermal noise and co-channel interference into account. The reported results are supported by network layer measurements of the number of RREQs packets broadcasted, received and rebroadcasted by all nodes.

3.1. Simulation setup

We used the ns-2 simulator (2.35v) [33] to analyze the performance of the fixed-probabilistic and the distance-based broadcasting schemes under realistic thermal noise and co-channel interference in noisy MANETs. AODV is the most widely used on-demand routing protocol [9,34] and it uses pure flooding as its broadcasting mechanism for route discovery. We modified the standard AODV routing protocol to AODV-P and AODV-D by incorporating the fixed-probabilistic and the distance-based broadcasting schemes respectively. Here P in AODV-P denotes the rebroadcast probability while D in AODV-D denotes the distance threshold. A rebroadcasting node estimates its distance d from the sending node by using the signal strength of the received RREQ packet. The simulation parameters generally follow [24,35]. The network bandwidth is set to 6 Mbps and the medium access control (MAC) protocol is simulated using the ns2 library dei80211mr [36]. This library calculates the PER using pre-determined curves (PER Vs. SINR) for a given packet size. Fig. 2 shows the PER Vs. SINR curve [36] used in our simulations. The SINR value is computed from the received signal strength, thermal noise and co-channel interference. Thermal noise is set to -95 dBm following the recommendation in [37].

The scenario consists of a fixed number of MANET nodes placed randomly in an area of 1000×1000 m^2. MANET nodes move according to the Random Waypoint mobility model [38] with a maximum speed of 10 m/s and the pause time set to zero. To consider the effects on the application layer, FTP (File Transfer Protocol) agents are attached to nodes such that node i is downloading a file of infinite size from node $i + N/2$ for $i = 1,2,\ldots,N/2$ where $N = 100$ is the total number of nodes. For energy consumption analysis,

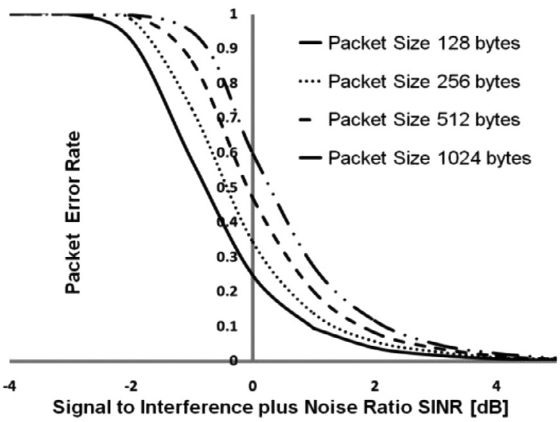

Fig. 2. Relationship between PER and SINR for different packet sizes [36].

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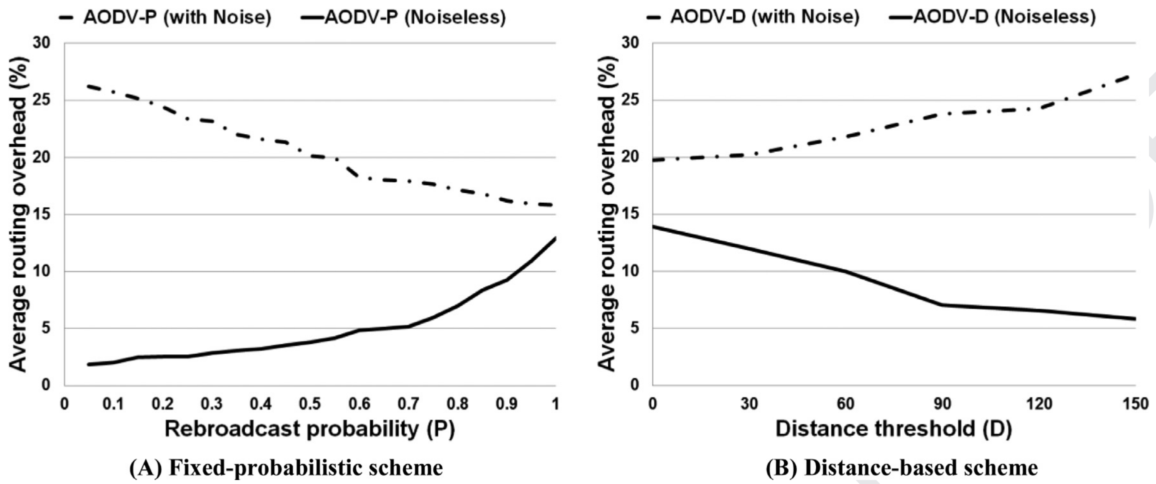

Fig. 3. Average routing overhead versus (A) rebroadcast probabilities, (B) distance threshold.

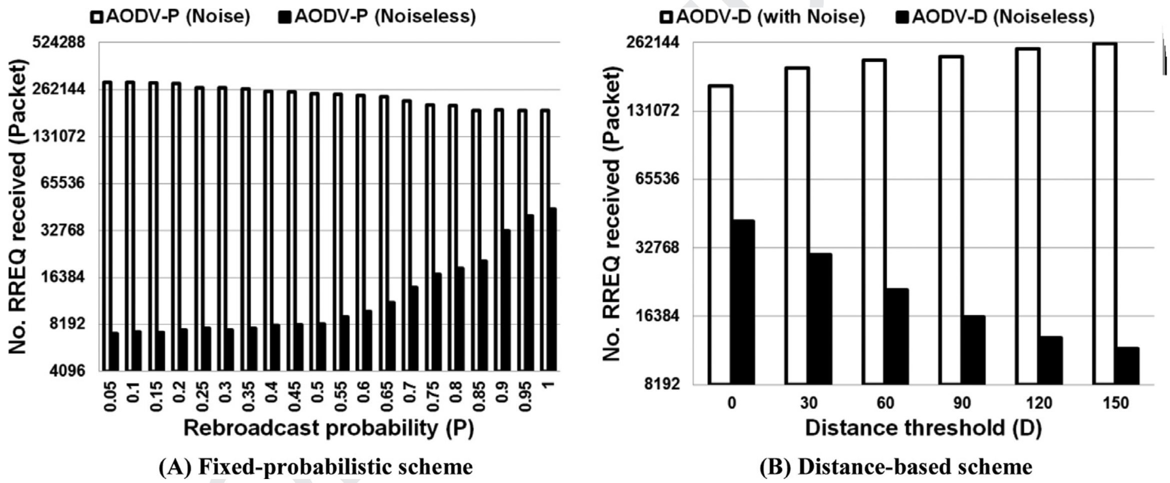

Fig. 4. Number of RREQ received versus (A) rebroadcast probabilities, (B) distance threshold.

each node has initial energy of 1000 J. Transmission power, path loss and received power threshold are set such that the effective transmission range is 250 m.

3.2. Simulation results and analysis

Simulation results are obtained by averaging the results of 30 runs, each using a different seed value and lasting for 800 s. The seed value is used to set the initial location of MANET nodes within the area. The aforementioned performance metrics (routing overhead, throughput, end-to-end delay and energy consumption) were measured for varying the value of rebroadcast probability P for the AODV-P scheme and by varying the distance threshold D for AODV-D scheme with and without thermal noise and co-channel interference. In the discussion below, term noise will be used to refer to thermal noise and co-channel interference.

3.2.1. Routing overhead

Routing overhead is defined as the number of routing packets (control packets) transmitted per data packet received. Fig. 3 depicts the average routing overhead for both AODV-P and AODV-D schemes in noisy and noiseless MANETs. It can be seen that for the noiseless case, the average routing overhead increases with P (in case of AODV-P) and it decreases with D (in case of AODV-D). This relationship is reversed when noise is taken into account for both AODV-P and AODV-D schemes. This can be explained by exploring the routing traffic. Let's consider the noiseless case first. By increasing the value of P or decreasing the value of D, the number of RREQs rebroadcasted and hence the number of RREQs received both increase (see Figs. 4 and 6). This increases the reachability of RREQs maximizing the chances of finding a valid route in the first attempt. That's why the total number of route requests, as denoted by the number of RREQ packets broadcasted, initiated by all nodes decreases by increasing the value of *P* or by decreasing value of *D* (see Fig. 5). However, the downside is that many nodes receive multiple copies of the same RREQ from different neighbors. The redundant RREQ traffic increases with increasing the value of *P* or by decreasing the value of *D* leading to higher routing overhead.

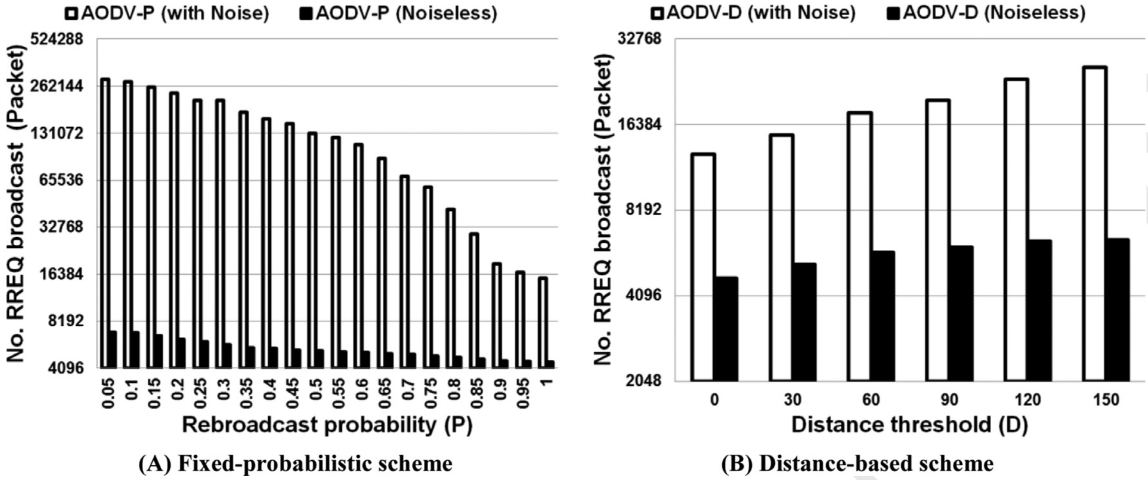

Fig. 5. Number of RREQ broadcast versus (A) rebroadcast probabilities, (B) distance threshold.

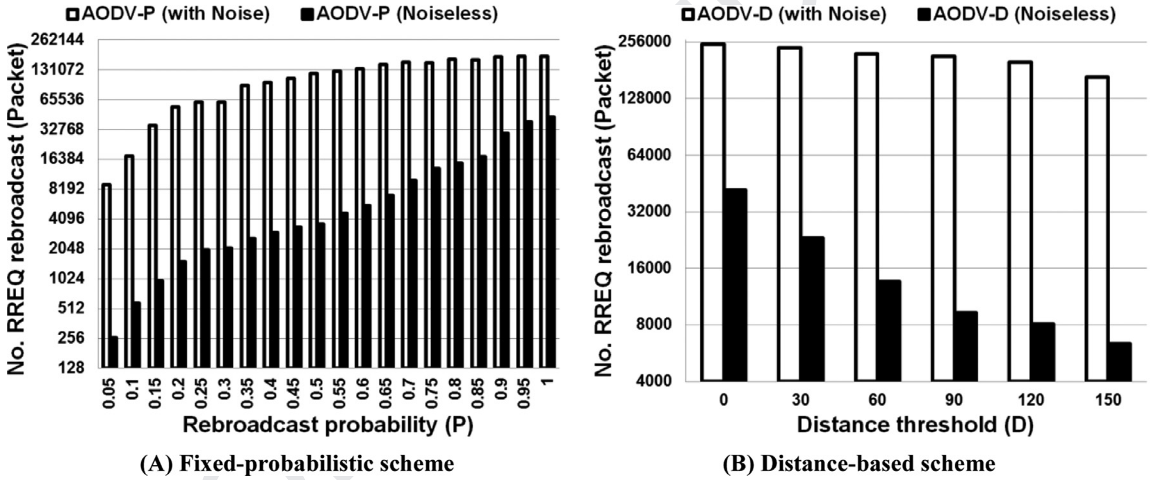

Fig. 6. Number of RREQ rebroadcast versus (A) rebroadcast probabilities, (B) distance threshold.

Now let's consider the noisy case. Both thermal noise and co-channel interference cause bit errors leading to packet losses. Thermal noise is independent of the traffic while co-channel interference increases with the traffic intensity. Increasing the value of P or decreasing the value of D may increase the reachability of RREQs on one hand but it increases the co-channel interference, on other hand, leading to higher packet loss rate. This can be confirmed by observing that with increasing value of P or decreasing value of D, the number of rebroadcasted RREQs increases but the number of received RREQs decreases due to higher packet loss rate (see Figs. 4 and 6). The fewer received RREQs limit the number of rebroadcasted RREQs as well. This explains why the number of rebroadcast packets increases with P at a lower rate for the noisy case compared to the noiseless case (see Fig. 6). In fact, thermal noise and co-channel interference act as natural limiters for the traffic; the former is static while the latter is adaptive because it increases with traffic intensity. This reduces the chances of getting duplicate RREQs from the neighboring nodes and adapts to the traffic intensity very well. In presence of natural and adaptive limiters (thermal noise and co-channel interference), the artificial limiters (reducing the rebroadcast probability or rebroadcasting only from distant nodes) do not work well because it limits the reachability of RREQs independent of the traffic intensity and channel conditions. Nodes have to try several times before they get a valid route which increases the routing overhead.

3.2.2. Average throughput

Throughput is defined as the amount of data received by a node per unit time. Fig. 7 shows that for any given value of P (or D), the throughput of noiseless AODV-P (or AODV-D) is much lower than the noisy AODV-P (or AODV-D) scheme. This is trivial and can be explained by considering the packet losses caused by the noise. However, the important point here is the difference in how throughput changes with P (or D) for noisy and noiseless AODV-P (or AODV-D). For noiseless AODV-P, throughput increases with P, reaches a maximum value and then starts decreasing but the throughput of noisy AODV-P increases monotonically with P and is maximum at $P = 1$ which is pure AODV. Similarly, throughput increases monotonically with D for noiseless AODV-D while it decreases monotonically with D for noisy AODV-D. This shows that the throughput performance of AODV-P

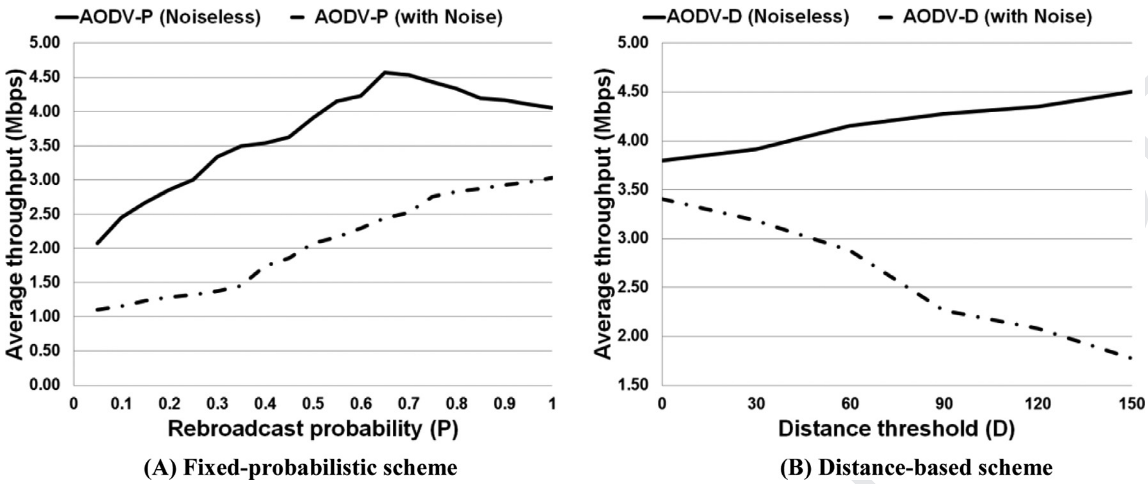

Fig. 7. Average of throughput versus (A) rebroadcast probabilities, (B) distance threshold.

and AODV-D is almost reversed when noise is taken into account.

Lower values of *P* limit the reachability of RREQs. As a result, the route discovery mechanism may not be successful at first attempt and may have to be initiated repeatedly. This would increase the time to establish a route from the source node to the destination node. The FTP application has to wait longer before it could start sending data. Moreover, node mobility invalidates old routes more frequently and interrupts the data supply until an alternative route is established. The lower the rebroadcast probability will be, the longer it will take to find the alternative route. This results in prolonged interruption in data supply that decreases the throughput further. Increasing the rebroadcast probability increases the reachability of RREQs and hence the throughput improves. However, beyond certain value ($P > 0.65$), the nodes start getting significantly higher number of duplicate RREQs from neighboring nodes that cost network bandwidth and the application layer throughput starts reducing from the peak value of 4.5 Mbps. For AODV-D, by increasing the value of *D* the number of RREQ packets decreases significantly (see Figs. 4, 5 and 6) that helps to improve the throughput.

In presence of noise, the strategy of limiting RREQ rebroadcasting harms the performance rather than improving it. It is because the decision of rebroadcasting RREQ packets is taken without taking the channel conditions and current traffic into account. In presence of noise, the throughput increases by increasing the value of P for AODV-P, even beyond $P = 0.65$, and by decreasing the value of D in AODV-D. In fact, the side effects of generating redundant RREQ packets by increasing the value of *P* or decreasing the value of *D* are diminished by noise itself because it acts as a natural limiters as explained in Section 3.2.1.

3.2.3. Average end-to-end delay

Average end-to-end delay shows the time a data packet takes to arrive from the source node to the destination node and includes all possible delays caused by route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, propagation delay and transmission delay at all intermediate nodes. Fig. 8 shows the average

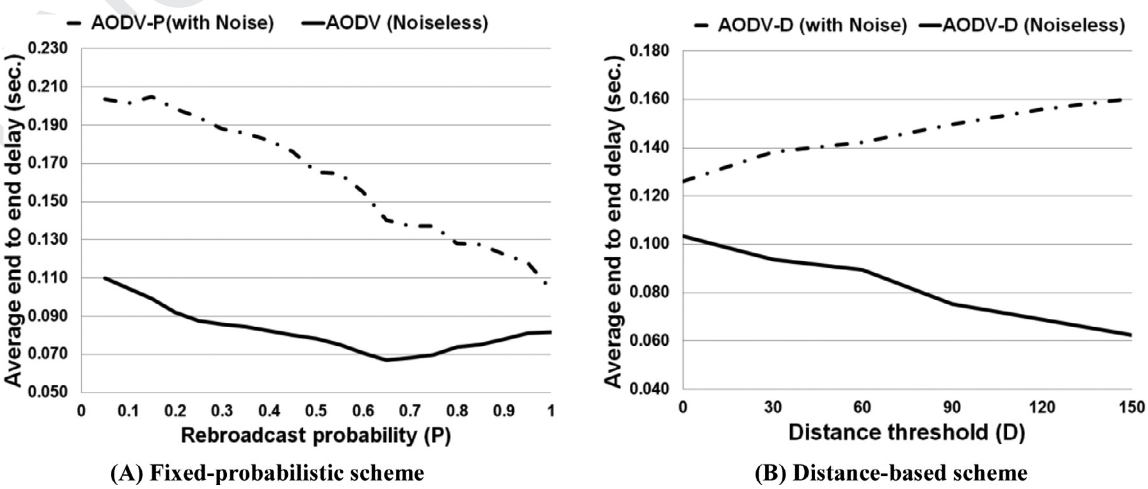

Fig. 8. Average end-to-end delay versus (A) rebroadcast probabilities, (B) distance threshold.

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end-to-end delay for data packets for all nodes. It can be seen that for any given value of P (or D), the end-to-end delay of noiseless AODV-P (or AODV-D) is much higher than the noisy AODV-P (or AODV-D) schemes. Similar to the throughput case, it is trivial and can be explained by considering the packet losses caused by the noise. However, the effect of the increasing value of P and D on end-to-end delay using AODV-P and AODV-D respectively is almost reversed when noise is taken into account.

Lower values of P (or higher values of D) limit the reachability of RREQ packets and the route discovery may fail. Consequently, the route discovery may need to be tried several times to get a valid route which increases the end-to-end delay. Higher values of P (or lower values of D) generate excessively large number of RREQ packets which contest with the application layer traffic and consume bandwidth. As a result the end-to-end delay is increased. However, when noise is considered in the simulation, excessive RREQ packets are lost due to interference and do not reach to other parts of the network for rebroadcasting avoiding the broadcast storm problem. That's why the end-to-end delay is not penalized by increasing the value of P (or decreasing the value of D).

3.2.4. Average energy consumption

Energy consumption accounts for the energy consumed in transmitting, forwarding and receiving of application layer data and routing-related control data. Fig. 9 depicts the average energy consumption of all nodes as a function of rebroadcast probability P and distance threshold D. For any value of P, the energy consumption of noisy AODV-P is higher than that of noiseless AODV-P. Similarly, for any value of D, the energy consumption of noisy AODV-D is higher than that of noiseless AODV-D. This is because, first, extra energy is consumed to compensate losses, second, the routing overhead in presence of noise is much higher than that of the noiseless case (see Fig. 3). This can also be verified by the total number of RREQ packets (broadcasted and rebroadcasted) which are much higher in the noisy case than that of the noiseless case (see Figs. 4– 6).

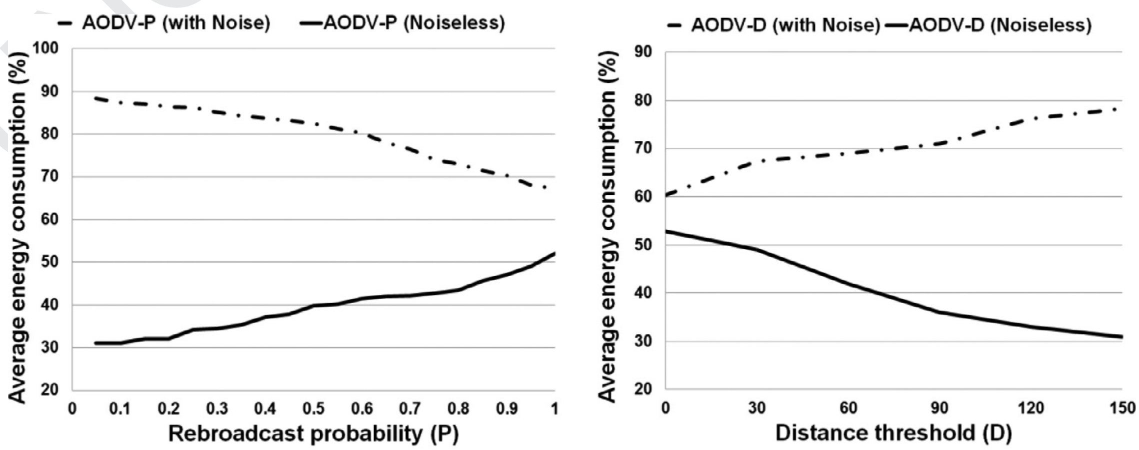
In the noiseless case, by increasing the value of P or decreasing the value of D, the energy consumption increases but in noisy case it decreases. This is perfectly aligned with the routing overhead that increases in noiseless case but decreases in the noisy case by increasing the value of P or decreasing the value of D. In fact, for the noiseless case, by increasing the value of P (or decreasing the value of D), even though the reachability of RREQ increases but the RREQ traffic shoots up exponentially which is more devastating in terms of energy consumption. When noise is taken into account, increasing the value of P (and decreasing the value of D) does not cause RREQ traffic to shoot up because noise acts as a natural limiter, excessive RREQ traffic is dropped due to inference and does not propagate further which reduces the energy consumption.

4. Conclusion and future work

Broadcasting is often used in on-demand routing protocols to discover new routes in MANETs. A number of probabilistic broadcasting schemes have been presented in the literature to limit the number of broadcast messages. However, these approaches were not evaluated under realistic conditions and have ignored the effects of thermal noise and co-channel interference which are inherent to real life MANETs.

This paper studied the effects of thermal noise and co-channel interference on the performance of two probabilistic schemes from the literature, namely fixed-probabilistic and distance-based broadcast schemes. We adopted the dei80211mr library of ns-2 based on the standard 802.11 g MAC layer protocol. This library uses SINR-based packet level error model by considering thermal noise and co-channel interference. The standard AODV routing protocol was modified to AODV-P and AODV-D by integrating fixed-probabilistic and distance-based broadcasting schemes respectively. The performance metrics included routing overhead, throughput, end-to-end delay and energy consumption.

The ns-2 simulation results revealed that, in contrast to the previous studies, fixed-probabilistic and distance-based broadcasting schemes performed worse than the pure flooding based scheme when thermal noise and co-channel



(A) Fixed-probabilistic scheme **(B) Distance-based scheme**

Fig. 9. Average energy consumption versus (A) rebroadcast probabilities, (B)d threshold.

interference were taken into account. The simulation results revealed the fundamental problem of fixed- probabilistic and distance-based broadcasting schemes that these schemes try to avoid the broadcast storm problem by limiting the rebroadcasting of RREQs statically and independent of the current traffic intensity. As a result, it may help in some cases while penalize in other cases. In fact co-channel interference acts as an adaptive limiter for traffic and sheds the extra traffic only when the system is overloaded by bursts of RREQs. The performance of AODV deteriorates with fixed-probabilistic and distance-broadcasting schemes when thermal noise and co-channel interference are taken into account. As part of ongoing studies, effects of thermal noise and co-channel interference on dynamic probabilistic schemes will be investigated.

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Please cite this article as: H.Y. Adarbah et al., Impact of noise and interference on probabilistic broadcast schemes in mobile ad-hoc networks, Computer Networks (2015), http://dx.doi.org/10.1016/j.comnet.2015.06.013

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Please cite this article as: H.Y. Adarbah et al., Impact of noise and interference on probabilistic broadcast schemes in mobile ad-hoc networks, Computer Networks (2015), http://dx.doi.org/10.1016/j.comnet.2015.06.013