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Energy evaluation of AID protocol in Mobile Ad Hoc Networks

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ABSTRACT

Mobile Ad Hoc Networks (MANETs) are communication networks formed on the fly by radio-equipped mobile nodes without relying on any fixed infrastructure. Flooding is the simplest technique for information dissemination in ad hoc based networks, in which nodes disseminate a received message to all their neighbors. This algorithm leads to the broadcast storm problem that severely affects the energy consumption due to redundant submissions. To regulate redundant submissions, which can cause more collisions and requires more energy, recently there have been developed numerous broadcasting techniques. These techniques have been mainly proposed to solve the storm problem by preventing certain nodes from rebroadcasting received messages and/or by differentiating the timing of rebroadcasts. In this paper, we have evaluated and compared an adaptive information dissemination (AID) algorithm with other MANETs broadcasting protocols with respect to the energy efficiency. In AID, each node can dynamically adjust the values of its local parameters using information from neighboring nodes without requiring any additional effort, such as distance measurements or exact location-determination of nodes. Simulation results are reported and show that adaptive broadcasting schemes are most efficient with respect to save broadcast, energy consumption, and reachability.

1. Introduction

The MANETs, being as decentralized type of wireless networks, do not rely on a preexisting infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, in MANETs each node participates in routing procedure as a router (not only as a host) by forwarding data to other nodes (Loo et al., 2011; Hamrioui et al., 2014). The forwarding decision is made dynamically based on the broadcasting/routing algorithms. It is worth noting that dissemination/broadcasting is an essential building block for most MANET protocols. For example, most unicast (Johnson and Maltz, 1996), multicast (Lee et al., 2002) and geocast (Camp and Liu, 2003) routing protocols use broadcasting to establish routes or to transmit an error packet for an invalid route (Colagrosso, 2007). Since communication range of nodes is limited and nodes are battery powered, optimizing energy consumption is one of the key factors when developing broadcasting algorithms. In order to save the transmission energy the number of redundantly received messages should be minimized, while, at the same time, maintaining good latency and reachability, since rebroadcasting causes tradeoff between reachability and efficiency under different host densities. Therefore, the selection of relay nodes and their transmission power is a major design consideration in routing and broadcasting algorithms (Bakhouya et al., 2011).

Generally, energy consumption of network devices can be proportional to power and time spent for sending, receiving or discarding the messages. As mentioned in Loo et al. (2011), energy efficiency is equivalent to the ratio of performance, measured as the rate of work done, to the power used and the performance can be represented by response time or throughput of the computing system. In other words, energy efficiency can be measured relatively to the network performance and intensively proportional to consumed power. Consequently, the main approach towards energy-efficiency is efficient power management. Thus, there can be two ways to enhance energy-efficient computing: either improving the performance with the same power, or reducing power consumption without sacrificing too much performance.

Ad hoc network is one of such systems, where the energy efficiency study in design of broadcast protocols has received significant attention in recent years. Due to the fact that mobile nodes are generally battery powered, the energy presents a very scarce resource. Therefore, the limited battery life time imposes

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constraints on the network performance. It is also important to mention that a key consideration for any energy-efficient protocol is the energy consumption at a wireless node (Ahlam Hashim et al., 2012; Wan et al., 2013, 2015). With respect to network activities, each node's radio can be in one of the following three states (Zhang et al., 2010): transmitting (with power TxPower), receiving (RtPower) and idle (idlePower): although no message is being transmitted, the node stays idle and keeps listening the medium, consuming energy at a rate that corresponds to an idlePower. In general, sending is more expensive than receiving, which in turn is more expensive than operating in idle mode. When a node transmits one packet, because of shared nature of wireless medium, all its neighbors receive this packet even if it is intended to only one of them. Hence, in order to maximize the network performance, the broadcasting protocols should be designed in an efficient way that the energy consumption is minimized.

Over the past few years, several broadcasting protocols have been proposed for MANETs (Miranda, 2007; Ni et al., 1999; Williams and Camp, 2002; Wieselthier et al., 2000), and energy efficiency problem has been considered in several studies (Cheng et al., 2003; Li et al., 2004; Ezzedine et al., 2009; Wieselthier et al., 2000). For example, in Cheng et al. (2003) authors introduced energy-efficient broadcast routing algorithms called minimum longest edge (MLE) and minimum weight incremental arborescence (MWIA). Authors achieved longer network lifetime by using MLE, i.e., minimizing the maximum transmission power of individual nodes. Broadcast incremental power (BIP) algorithm developed and then adapted to multicast operation in Wieselthier et al. (2000), exploits the broadcast nature of the wireless communication environment and addresses the need for energy-efficient operation. This algorithm takes into account the wireless broadcast advantage in the formation of low-energy broadcast trees, and it is a node-based spanning tree algorithm, which means transmission power needed to reach all its direct children. Energy and latency efficiencies are targeted in Ezzedine et al. (2009) in the design of ELE-MAC protocol, which attempts to minimize the energy wasted by control packets and to decrease latency.

To achieve maximal performance level in broadcasting process there have been done numerous research in design of protocols in MANETs (Ni et al., 1999), and each protocol presents some advantages and suffers from some drawbacks. In this paper we evaluate and compare the performances of existing protocols with an adaptive protocol for information dissemination for VANETs, presented in our previous work (Bakhouya et al., 2011). The remainder of this paper is structured as follows. We will first present the protocols used in MANETs for broadcasting purpose, a short description of each protocol will be provided in Section 2 followed by a brief description of adaptive broadcasting protocol, called AID, in Section 3. Section 4 presents the simulation results by mainly focusing on energy efficiency in term of reduced number of retransmissions. Conclusions and future work are presented in Section 5.

2. Related work

Broadcasting protocols for MANETs can be classified into two main categories: *static protocols* and *adaptive protocols*. Static protocols can be in turn classified in two sub-categories: *statistical or geometric based* and *network topology based* protocols as shown in Fig. 1. Geometric-based protocols category depends upon certain threshold (e.g. distance, redundant message counts, or broadcast probability) values to estimate the network density while network topology-based protocols use sophisticated structures or neighborhood information to construct the broadcast schedule.

2.1. Static protocols

There are two main categories in this class of protocols, geometric-based and topology-based protocols. The statistical or geometric based protocols are also subdivided into: parameter-based and area-based. Parameter-based protocols use certain parameters, like broadcast probability and hope counters in order to reduce the number of redundantly received packets. The parameter based protocols basically extend the flooding technique, in which the source node disseminates a message to all its neighbors only if this message is seen first time. The classical flooding algorithm has several drawbacks; first it is rather costly in terms of air interface usage, secondly, it is not reliable since most of the nodes are expected to broadcast the message at the same time, thus collusions are likely to occur, thirdly, it causes broadcast storm problem (Ni et al., 1999) that severely affect the energy consumption due to redundant message re-broadcast. An example of optimal broadcasting schedules is depicted in Fig. 2 in which only two transmissions are enough to reach all nodes instead of seven transmissions when using the flooding (Ezzedine et al., 2009).

In counter-based broadcasting, a message will be rebroadcasted only if the number of received copies at host is less than a threshold after RDT (Random Delay Time, which is randomly chosen between 0 and T_{max} seconds) (Kim et al., 2008). In Huang et al. (2006), authors have modified the counter-based protocol and named the new protocol as Hop Count Ad hoc Broadcasting (HCAB) protocol. In probabilistic scheme, mobile hosts rebroadcast messages according to certain probability that is defined at the initial stage. The major drawback of this technique is that setting the probability dynamically in different traffic situations is not an easy task. In Zhang and Agrawal (2005), authors have introduced a scheme for dynamic probabilistic broadcasting in MANETs. The area-based broadcasting techniques, however, exploit the geographical location of the node to calculate the additional coverage area of the sender. More precisely, area-based information broadcasting schemes take advantage of the geo-graphical location of the nodes (Kouvatsos and Mkwawa, 2011). Two main approaches used in this category: distance-based and location-based. In the distance based approach, only the neighbor far away from the current node rebroadcasts the message i.e. a distance threshold value is defined a priori. The location-based scheme, however, uses a more precise estimation of expected additional coverage area in the rebroadcasting decision. The major drawback of this scheme is that nodes have to be equipped with GPS.

The network topology-based protocols are further categorized into structured and unstructured protocols. Structured protocols use geometrical shapes or data structure to make an information dissemination plan. They are classified into two main categories: cluster-based and spanning tree-based. Despite their usage in many applications, the cluster-based approach is also used for broadcasting in which mobile hosts form clusters. Within one cluster, each host is treated as a member, and there is one cluster head and one gateway node responsible for relaying messages. However, maintaining such structure is too costly or even impossible especially when the nodes mobility is very high. Furthermore, in a clustered MANET (Lloret et al., 2008a, 2008b), each node periodically sends 'Hello' message to advertise its presence which consume extra transmission energy. In Juttner and Magi (2005), authors have described a spanning tree based algorithm for broadcasting in ad hoc networks. The whole broadcasting mechanism is divided into two parts: i) the maintenance of the broadcast tree, and ii)

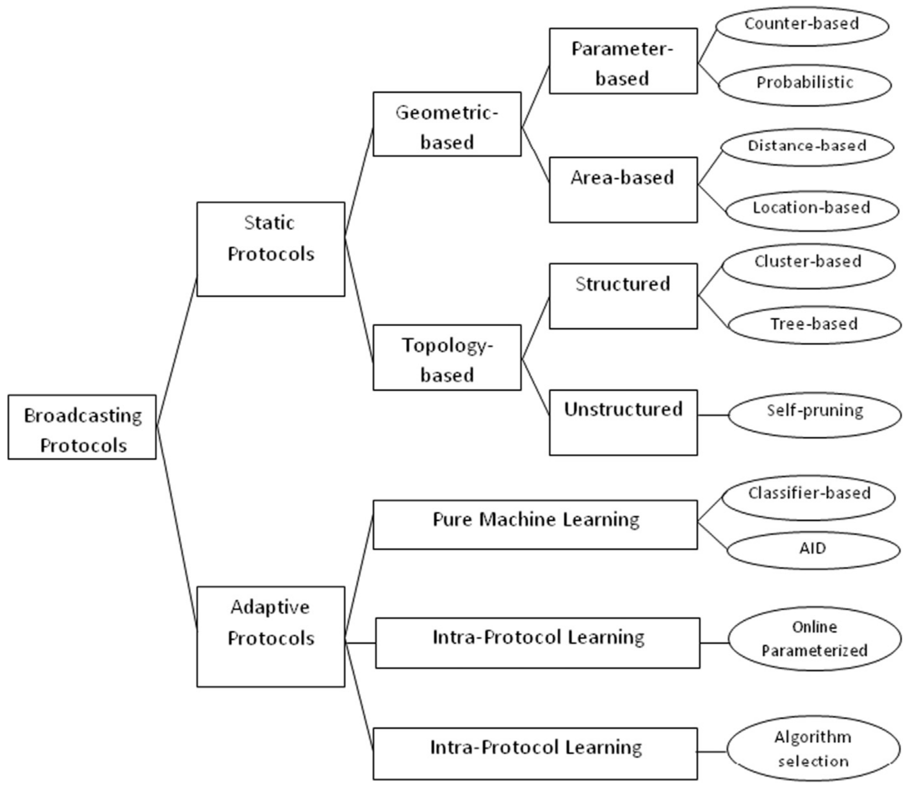

Fig. 1. The classification of broadcasting protocols used in MANETs.

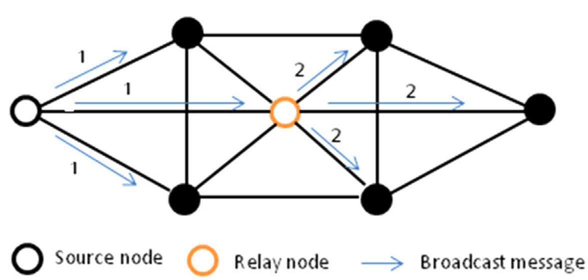

Fig. 2. An optimal broadcasting schedules (Ezzedine et al., 2009).

the broadcast process itself using the tree. The spanning tree based broadcast scheme is considered to be inappropriate for ad hoc networks, being too difficult and resource consuming and being too sensitive to the link failures.

Unstructured protocols, however, use neighborhood information to calculate the additional number of recipient nodes. Two main schemes are used for this purpose: self-pruning and scalable broadcasting. In self-pruning, each node maintains the knowledge of its neighbors by periodically exchanging the 'Hello' messages. The receiving node first compares its neighbors list to that of sender's list, and rebroadcast the message only if the receiving node can cover additional nodes. The neighbor knowledge attached with the identity of the node from which the packet is received allows a receiving node to decide if it would reach additional nodes by rebroadcasting. The scalable broadcasting further enhances the self-pruning scheme by gathering neighbors' information up to two hops distance. In all these schemes, there are no messages (i.e., additional overhead) that are exchanged between nodes. Each node is only using broadcast messages received from neighboring nodes to decide for either sending or inhibiting itself from rebroadcasting it.

2.2. Adaptive protocols

Static protocols are mainly based on various threshold parameters to help nodes to decide whether to rebroadcast or discard received messages. However, in dynamic networks, it is difficult even impossible to determine a priori these parameters. Adjusting these thresholds on-the-fly have been proposed in (Lloret et al., 2008a, 2008b; Tseng et al., 2003; Yassein et al., 2011; Medetov et al., 2014). For nodes to decide to retransmit or reject, they need local information obtained through periodical hello messages and from other protocols such as routing protocols. However, some additional fixed parameters, such as message generation time on the source, location (of source or/and intermediate nodes), time synchronization between nodes, and relativeness of information are used to adapt/adjust these thresholds.

Adaptive broadcasting algorithms that have been proposed in literature can be classified in three categories (Colagrosso, 2007): pure machine learning, intra-protocol learning, and inter-protocol learning. In pure machine learning, nodes learn to adapt to their environment and improve through experience. As an example, a broadcasting protocol in which a node builds a classifier using data collected from the network environment is proposed in Colagrosso (2007); the classifier is trained to select more efficiently to either rebroadcast or discard a received message. For each incoming packet, a node uses its local model to classify it as a positive (i.e., retransmit) or a negative (i.e., disregard). To do so, the concept of a successful retransmission of a broadcast packet is defined using an objective function to assess whether a given node is contributing to the delivery of broadcast packets. Each node estimates its own function and tunes its behavior accordingly in order to maximize it. Reported results show that this protocol outperforms other protocols by providing a high delivery ratio with low overhead under a range of network conditions. It is worth noting that a successful retransmission concept corresponds to a feedback loop, which is used for training the classifier.

Intra-protocol learning algorithms use online parameterized techniques in which nodes learn to change one of the parameters. For example, Random Assessment Delay (nodes chose a RAD randomly in the uniform range (0, Tmax)) is a parameter that was shown to be sensitive to the density of neighboring nodes and congestion (Peng and Lu, 2000; Williams and Camp, 2002). Authors in (Colagrosso, 2007) propose to use a simple model that allows each node to estimate the most suitable value of *Tmax* according to its local conditions. Other approaches propose to adjust parameters (thresholds values) using local information obtained through periodical hello messages and from other protocols, such as routing protocols (Tseng et al., 2003; Wan et al., 2013; Yassein et al., 2011).

In inter-protocol algorithms nodes can learn to switch between different broadcast protocols. For example, in Colagrosso (2007) authors propose an inter-protocol learner for nodes to automatically switch between two broadcasting protocols. In this approach, any combination of protocols, such as simple flooding, probabilistic, counter-based, distance-based, or location-based, would be a good candidate. Recently, we have developed an adaptive broadcasting approach, called AID (Bakhouya et al., 2011). The techniques adapted fall in the pure machine learning category and allow each node to dynamically adjust the values of its local parameters using information from neighboring nodes. Next section presents an overview of AID algorithm.

3. AID algorithm: an overview

It is worth noting, as stated above, that recent studies showed that there is no benefit to rebroadcast a message after heard it k times when $k \geq 4$, because the expected additional coverage area is below 0.05% (Ni et al., 1999). For example, in a counter-based scheme, a fixed threshold value C is used to inhibit nodes from rebroadcasting messages (Ni et al., 1999). Indeed, if a node already heard the same message more than C times, it is unlikely to rebroadcast the message because of negligible coverage area. So, it is imperative to have a control mechanism whereby the threshold C can be adjusted to balance between reachability and saving rebroadcast depending on dynamic changes of the topology (i.e., network density). For example, when nodes are located in a highly dense area, they may receive a lot messages causing the storm problem (Ni et al., 1999). Therefore, fixing parameters at each node and dynamically adjusting their values based on geographical distribution of nodes are required. In other words, in dense networks, multiple nodes share similar transmission coverage, and therefore some nodes does not need to retransmit (the threshold need to be low), and in sparse networks, there is much less shared coverage, some nodes have to retransmit (the threshold needs to be high).

In order to tackle these issues an Information Dissemination (AID) approach has been proposed in Bakhouya et al. (2011). This scheme allows nodes to select an appropriate action (i.e., rebroadcast, or discard) in distributed manner, i.e., without the aid of a central controller. AID is a decentralized and adaptive approach, in which each node, by receiving information from neighboring nodes, can dynamically make dissemination decision (re-broadcast or discard) without using any predetermined threshold values (as mentioned above for statistical- or geometric-based methods) or requiring any additional effort, such as distance measurements or exact location-determination of nodes. Based on the number of received messages, each individual node decides on rebroadcasting without the aid of a central controller using the following steps:

S_1. On hearing a broadcast message m for the first time at time t_a, the node initializes a counter c and a counter s.
S_2. Generate a random value τ (RDT) for M transmission.
$S_{2.1.}$ Wait until the transmission actually starts, i.e., until τ has expired. If m is received again at time t_b duringτ, go to $S_{2.2.}$ Whenτ has expired, if m was heard again (i.e., $c>0$), go to S_4, otherwise go to S_3.
$S_{2.2.}$ Increase the counter c by 1, and update the list ℓ by recording $\Delta t = (t_b - t_a)$, then go to $S_{2.1}$.
S_3. Rebroadcast m and procedure exit.
S_4.
$S_{4.1}$. For all the values Δt_irecorded in ℓ, compare each one of them with τ/c: when $(\tau/c) - \Delta t_i > 0$, decrease s by 1, otherwise increase it by 1.
$S_{4.2}$. If $s>0$, then go to S_3, else go to S_5.
S_5. Discard the transmission of m and the procedure exit.

On hearing a broadcast message for the first time, the node initializes a local counter c to 1 to keep track of the number of times the same message is received and waits for a random of slots τ (RDT). Another counter s, initializes to 0, is used to help nodes for deciding on the rebroadcast. A list ℓ is also used to track the inter-arrival times between successive messages Δt. Each time the same message is heard again, the counter c is increased by one and the node calculates the intensity of arrived messages Δt to be recorded in ℓ. In other words, a node receiving a message at time t_b extracts the value of the time of the last message received denoted by t_a, calculates a value $\Delta t = (t_b - t_a)$, and adds it to the list ℓ.

When the duration τ is expired, the Δt values of inter-arrival times between successive messages are compared with the value τ/c, considered as the mean inter-arrival time baseline. If Δt is greater than τ/c, the value s is increased by 1; otherwise it will be decreased by 1. When all values in the list ℓ are compared with τ/c, the node can decide to rebroadcast or discard the message based on the value of s.If s is below 0, the node discard the message, i.e., do not forward it to its neighboring nodes. On the other hand, if the value of s is greater or equal to 0, the node broadcasts the message. The value s is smaller than 0 means that several inter-arrival times are smaller than τ/c, which is interpreted by an excessive number of received broadcast messages. Each node adjusts its own value s depending on its local information based on the number of times the message is received and the inter-arrival times between two successive messages. When the slot time τ expires, the node decides to re-broadcast or discard the received message.

Adjusting the value s is based on the following principle. When a node receives few messages (c is small), in order to cover a larger area nodes should rebroadcast the message, because the node might have a few neighbors (sparse network). Inhibiting the node from rebroadcasting heard message may cause less reachability. So, when c is small, the inter-arrival time may be greater than τ/c, and therefore s is greater than 0 causing the node to rebroadcast the message in order to achieve better reachability. In other words, when the time of inter-arrival of messages is large, it means that there are a sub-optimal number of rebroadcasts, and therefore, the node should retransmit the message. However, when c is large, this means that the node might have many neighbors with an excessive number of rebroadcasts. Therefore, the inter-arrival time of messages may be smaller than τ/c causing the node to discard the message. This decision will not affect the reachability but increases save rebroadcasting value and hence decreases consumption of transmission energy. In summary, as shown in Fig. 3, each node adjusts its own value s depending on local

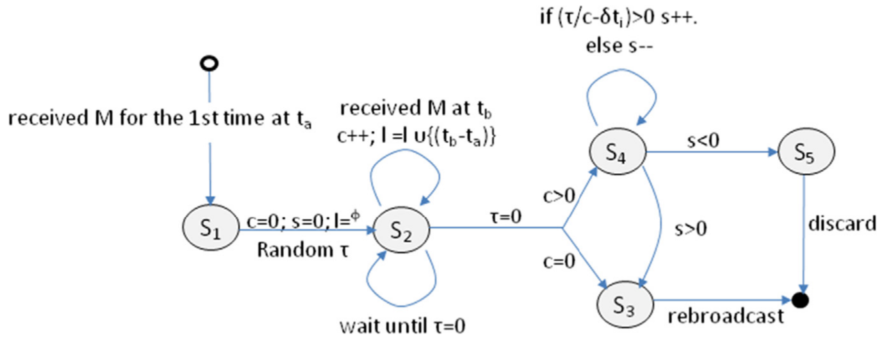

Fig. 3. The graphical view of AID algorithm.

Table 1
Simulation parameters.

Simulation parameter	Value
Network range	1500 m^2
Transmission range	250 m
Number of nodes	50–100
Bandwidth	2Mbps
Message size	1000 bytes
Simulation time	100 s
Number of trials	10
RtPower, TxPower, idlePower	10, 15, 0.5
TransitionPower, transitionTime	0.2, 0.005
SleepPower	0.001
Initial energy	100 J

information based on the number of times a message is received and the inter-arrival times between two successive messages. When the fixed slot time expires, the node decides to re-broadcast or discard a message.

4. Performance analysis

This section focuses on evaluating and comparing energy consumption of statistical-based broadcasting schemes, with AID approach presented above. Energy consumption of each node during the simulation is measured using the energy model provided by the NS-2 simulator. We measured and compared the performance of AID algorithm with two distinguished broadcasting protocols (probabilistic-, and distance-based) under different host densities. Different threshold values for the protocols investigated are defined as follows: for probabilistic-based, the relay probability is set to 0.1, 0.5, 1; for distance-based, the distance threshold is set to 50 m, 150 m, and 250 m (equal to transmission range). We mainly investigate the effect of nodes density within the range from 50 (as a sparse network) to 100 nodes (as a dense network) where nodes speed is fixed to 5 m/s. A simulation time of 100 s was used; it was long enough to evaluate the broadcasting protocols by varying node speed and densities. Each node use the IEEE 802.11 MAC protocol to send and receive messages. We used a two-ray ground model for radio propagation, network range of 1500 m × 1500 m, bandwidth equal to 2 Mbps, transmission range equal to 250 m, Initial Energy equal to 100 J, and message size equal to 1000 bytes. Simulation parameters are described in Table 1.

The key performance metric that we are interested to measure is the Saved ReBroadcast (SRB) which is the ratio between the number of hosts receiving the message and the number of hosts actually rebroadcasting the message. Since our goal is to measure the transmission energy consumption against each protocol, the number of SRB is inversely proportional to the transmission energy. So the greater number of SRB will represent the lesser transmission energy consumed during the broadcasting. Another metric we have observed is Reachability: the number of mobile nodes receiving the broadcast message divided by the total number of mobile nodes that are reachable, directly or indirectly, from the source node. We performed several simulation trials for each scenario and calculated the average number of SRB, remaining energy and reachability against each investigated scheme.

Fig. 4 shows the SRB, the energy consumption, and the percentage of nodes actually received the message, respectively. As shown in Fig. 4a, for distance-based protocol, as distance increases the SRB increases, because only the neighbor far away from the current node rebroadcasts the message. For example, a higher SRB is shown when the distance threshold is equal to the transmission range 250 m. As expected, rebroadcasting causes tradeoff between energy efficiency. As more rebroadcast sent, more energy is consumed. For example, the SRB when the distance threshold is 50 m, more messages are submitted, and then more energy is consumed (Fig. 4b), but higher reachability (Fig. 4c) is achieved. When the distance threshold is higher (250 m), fewer messages are sent, and therefore reachability is suffered to low level, but less energy consumption is achieved.

In probabilistic-based protocol, as the threshold value increases, more messages are rebroadcasted (the threshold value equal 1, prob-1, corresponds to flooding protocol), which means higher reachability is achieved, but for that more energy is consumed. The flooding (prob-1) shows the worst behavior in both sparse and dense networks, almost all nodes have rebroadcasted the message (lower SRB) to achieve higher reachability, but more energy is consumed. Under different nodes density, AID has significant SRB, less energy consumption, and higher reachability, as compared to other schemes except in some cases as follows. Distance- and probability-based protocols have higher SRB than AID scheme with critical threshold values, such as dist-250 m and prob-1, which caused to the lowest reachability, while an AID scheme has very good reachability (almost 100%) by consuming almost same transmission energy.

When we fixed distance threshold as 50 m almost all nodes participated (Fig. 4a) in message dissemination process, resulted in good reachability (Fig. 4b), but, consumed more energy (Fig. 4c). Similar situation can be observed when we selected 150 m as a threshold for distance; only about 30% of nodes have saved from rebroadcasting (almost same with AID) in sparse networks, but in dense networks only about 10% saved while five time more SRB stated in AID to reach practically same level of reachability and significantly more energy is saved by AID. Over-using transmission energy could result in shorter lifetime for the whole network. These obtained results justify the effectiveness of the AID scheme,

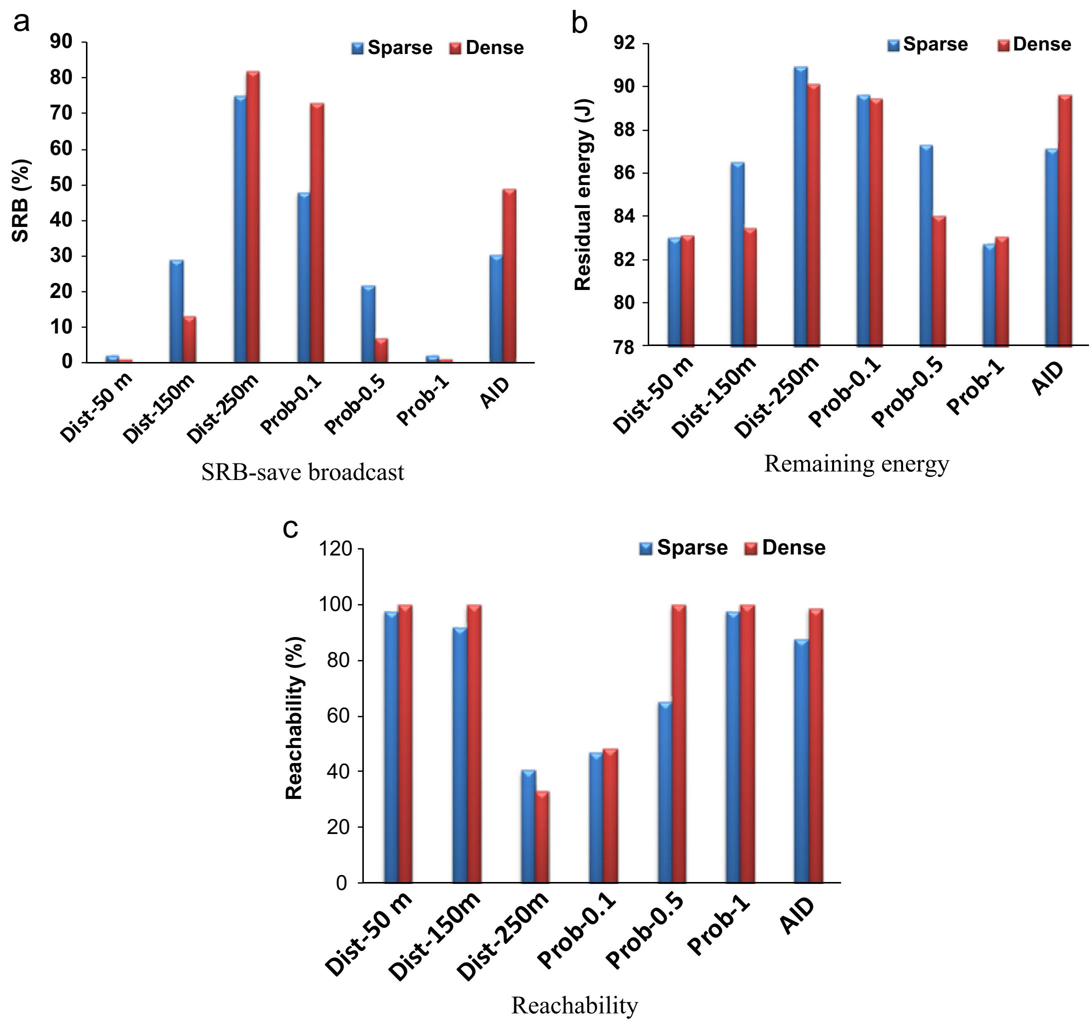

Fig. 4. Evaluation of AID with probabilistic and distance based algorithms. (a) SRB-save broadcast, (b) remaining energy and (c) reachability.

i.e., without using any fixed threshold, over probabilistic- and distance-based schemes.

5. Conclusions and future work

MANET nodes have limited battery charging capacity that requires energy efficient protocols especially for broadcast purpose since broadcast operation requires subsequent routing and re-transmissions in order to disseminate the information among all network nodes. In this paper, we first surveyed the most common broadcast protocols that are used in MANETs. Since our main objective was to find the most efficient protocol with respect to energy consumption, we selected three potential protocols to measure their performance in terms of communication over-head i.e. the number of re-transmissions, reachability and energy consumption during the broadcast operation. The effectiveness of these protocols has been proved by simulation experiments using network simulator NS2. As expected, AID has significant SRB, less energy consumption, and higher reachability, when compared to distance- and probability-based protocols. It is the most efficient with respect to SRB both in terms of network density and nodes mobility. It provides a near-optimal solution in terms of maximum SRB and average latency while maintaining good reachability. Ongoing work concerns the comparison of this algorithm with other adaptive techniques (Harutyunyan and Opatrny, 2014; Ali Khan et al., 2011) that are used in intra- and inter-protocol learning algorithms (Williams and Camp, 2002). Furthermore, we are investigating swarm and artificial intelligence (Bakhouya and Gaber, 2014; Maity and Hati, 2012) and its applications as a great source of inspiration for developing adaptive approaches in Ad hoc Networks.

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