Hybrid Flooding Scheme for Mobile Ad Hoc Networks

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***Abstract*—A hybrid broadcast scheme for mobile wireless networks is proposed in this letter. The main objective is to combine different flooding schemes in order to solve the broadcast storm issue encountered by the simple flooding scheme. For this purpose, the density of nodes is taken into account using a density metric called expansion metric. In addition, in order to reduce the broken links due to mobility of nodes and increasing dissimilarity among the intermediate nodes, a forwarding zone criterion is included in the proposed schemes. The proposed approaches have been implemented and compared with pure probabilistic flooding, and simple flooding schemes.**

***Index Terms*—Flooding, MANETs, WSNs, density.**

I. Introduction

FLOODING is a popular broadcast scheme used during the discovery phase of most Mobile Ad Hoc Network (MANET) routing protocols. In simple flooding technique each intermediate node forwards the incoming packet until it reaches the destination node. The simplicity of flooding makes it suitable for resource constrained networks such as MANETs or Wireless Sensor Networks (WSNs). Flooding schemes can be classified into four groups [1]: (1) simple or blind flooding, (2) probabilistic or gossip flooding [2], (3) area based flooding [3], and (4) neighbor knowledge flooding [4]. Simple flooding causes a high network routing load in the network due to the broadcast storm problem [2], and as a result consumes high energy. Probabilistic flooding scheme has been proved to be more efficient than the simple flooding scheme [2]. However, the main challenge in the probabilistic scheme is to find the optimum probability P of the forwarded packets. One way of establishing the optimum value for P is using simulations for a typical wireless scenario. However, as this optimum value for P could vary from scenario to scenario, this would require repeated simulations for all possible scenarios being considered. Therefore, it is not practical to identify a single optimum value for P. In [2] the authors established that the optimum value for P lies within the interval [0.65, 0.75] in networks with fewer than 1000 nodes. They also proposed P = 0.5 as an optimum value for network scenarios with certain node densities (150 nodes in a rectangular grid of 1650 x 1200 m2). Furthermore, it has also been demonstrated that for high node densities, the value of P should be set at lower values to avoid redundant packets. On the other hand, if the node density is low the value of P should be set higher to avoid die out problem [2]. Area based methods suffer from nodes' mobility since nodes should update their locations periodically which causes an additional overhead [5]. Neighbor knowledge scheme uses information on neighboring nodes in order to group the nodes in clusters. This scheme has reduced overhead for low mobility networks; however it is not suitable for high mobility networks. Most neighbor knowledge schemes also insert a list of neighbor's IDs, which increases the overhead in the request packets. In this letter, a hybrid solution is proposed with the aim to reducing the overheads in mobile networks using an adaptive probabilistic flooding scheme based on neighbor knowledge and a forwarding zone criterion. The term 'expansion metric' (defined below), which differentiates the density of nodes in different areas of the deployed scenario is defined to measure the neighborhood information. In addition, a forwarding zone criterion has been defined to control the forwarding probability. The forwarding zone criterion has two major objectives, (1) to reduce the control messages due to broken links, and (2) to detect the dissimilarity among the forwarding nodes and select the most dissimilar nodes. As a way of addressing the issues with neighbor knowledge schemes, the proposed scheme eliminates the need for the nodes to cache a node's ID. They only count the number of 1-hop and 2-hops neighbors in order to calculate the expansion metric, and the request packets contain only the expansion metric. Also the proposed approach does not delay the communications like some counter based schemes, since the nodes start to retransmit immediately after receiving the incoming request.

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II. Proposed Approach

The terminologies used in this letter are given below, see also Fig. 1:

- Node's degree (d): is the number of neighbors of a given node.
- 2-hops node's degree (d2h): is the number of neighbors of a given node's neighbors. This metric represents the number of neighbors which are two hops away from the node.
- Expansion metric (E): is a density metric which determines how dense the 2 hops neighborhood of a node is. It is calculated as follows

$$E = \frac{d_{2h}}{d} \quad (1)$$

In the neighbor knowledge scheme, when the nodes evaluate the equation (1), if an intermediate node has a high value for E, it will mean that its 2 hops neighborhood is dense. On the other hand, if the value of E is low, then its 2 hops neighborhood is not dense. Therefore, it can be safely

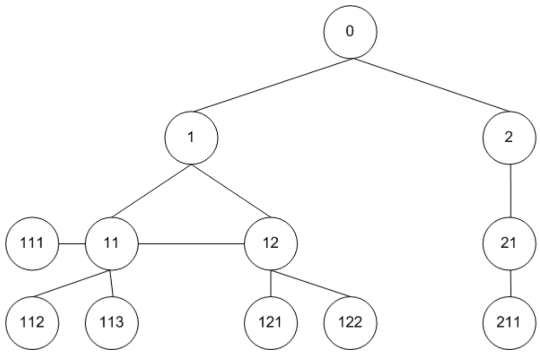

Fig. 1. A sample network with different degrees of connection.

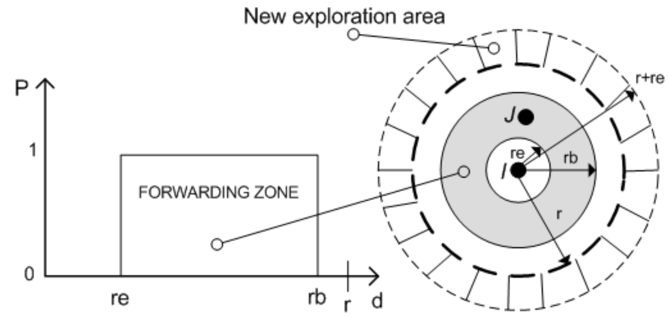

Fig. 2. Forwarding area as a distance filter.

concluded that the difference between two intermediate nodes' E-values represents the difference in densities between the nodes' 2 hops neighborhood. As mentioned earlier, in dense areas, the value of optimum probability P should be reduced due to the redundancy of control packets. As a result, the difference between the two values of E in a broadcast path could be considered as the metric that indicates whether the value of P should be increased or reduced along the broadcast path. In this letter the value of P is adjusted hop by hop depending on the value of E as shown below. The forwarding probability $P(E_t, E_{t-1})$ can be expressed as:

$$\begin{array}{ll} P(E_t, E_{t-1}) = P_i + P_d(E_t, E_{t-1}) & E_t < E_{t-1} \\ P(E_t, E_{t-1}) = P_i - P_d(E_t, E_{t-1}) & E_t > E_{t-1} \\ P(E_t, E_{t-1}) = P_i & E_t = E_{t-1} \end{array} \quad (2)$$

Where $P_d(E_t, E_{t-1})$ is the density dependent probability and P_i is the initial value of the probability for forwarding an incoming packet. Pi ensures reachability and avoids die out problem. E_t is the expansion metric at the intermediate nodes. Note that the broadcast decision is made based on 3 hops nodes' information. In order to clarify the proposed scheme, let us consider a sample network, as shown in Fig. 1

The node 0 is the source node in Fig. 1. A node's degree in its 2-hops neighborhood from the source node can be expressed as below:

$$\begin{array}{l} d(0) = \{1, 2\} = 2 \\ d(1) = \{0, 11, 12\} = 3 \\ d(2) = \{0, 21\} = 2 \\ d(11) = \{1, 12, 111, 112, 113\} = 5 \\ d(12) = \{1, 11, 121, 122\} = 4 \\ d(21) = \{2, 211\} = 2 \end{array}$$

Similarly, the 2-hops degrees for the source node 0, and the 1-hop neighbors 1, and 2 are given by the following expressions

$$\begin{array}{l} d_{2h}(0) = \{11, 12, 21\} = 3 \\ d_{2h}(1) = \{11, 12, 111, 112, 113, 121, 122, 2\} = 8 \\ d_{2h}(2) = \{1, 211\} = 2 \end{array}$$

The Expansion metrics for the nodes 0, 1, and 2 will be calculated using equation (1) and are given below:

$$\begin{array}{l} E(0) = \frac{3}{2} = 1.5 \\ E(1) = \frac{8}{3} = 2.6 \\ E(2) = \frac{2}{2} = 1 \end{array}$$

Applying the above values for E(0), E(1) and E(2) in the conditions for equation (2), the forwarding probabilities for nodes 1 and 2 are given by:

$$\begin{array}{l} P(1) = P_i - P_d \\ P(2) = P_i + P_d \end{array}$$

As a result, each node will adjust its forwarding probability anticipating the network's structure from its local point of view. However, in the above approach, the neighbors located closer to the broadcast node will not explore new areas since their transmission ranges are likely to cover the same area. So, the proposed density dependent approach has been improved by taking the distance among the nodes into account. Larger the distance between two nodes, the higher the dissimilarity between the nodes' neighbors is. However, mobile bordering nodes are likely to get out of the node's transmission area [6], and thus will cause broken links. Whenever a broken link occurs a new discovery phase should be started which in turn will increase the use of control messages. Therefore, an improved forwarding zone is proposed in this letter to improve the connectivity. The general principle of the proposed scheme is shown in Fig. 2. The x-axis represents the Euclidean distance d between two nodes I and J, I being the source node, and J a possible intermediate node located in the forwarding zone. The y-axis represents the forwarding probability P. This forwarding zone has two boundaries namely, r_b and r_e. While r_e determines the dissimilarity between the two nodes, r_b avoids including bordering nodes in new routes.

With r_e a new area of exploration $r_e = \pi((r+r_e)^2 - r^2\ m^2$ is guaranteed at each hop. Whereas, the value of r_e guarantees a minimum link's lifetime $= \frac{(r-r_b)}{V_{max}}$, where, V_{max} is the node's maximum speed. If the intermediate node is located outside the forwarding zone, the probability of forwarding the incoming packet is zero, see Fig. 2. Otherwise, the value of P is calculated using equation (2). In other words, the forwarding zone is used as a distance filter.

In order to evaluate these proposed approaches, they have been implemented over Ad Hoc On-Demand Distance Vector (AODV) routing protocol. This scheme uses simple flooding algorithm during the discovery phase to find a communication path from the source to the destination node. Several modifications have been made to the traditional AODV scheme in order to include the expansion metric and the forwarding zone approaches. The number of neighbors of a given node has been included in the HELLO packets. Notice that the nodes do not need to collect its entire neighbors' IDs, they only need the total number of the neighbors. The proposed approach uses only 5-6 additional bits within the Hello packets to include this information in networks with more than 100 nodes. This feature makes the proposed approach lighter than the other neighbor knowledge schemes [1]. The request packets (RREQs) include the node's expansion metric. When an intermediate node receives the RREQ, it calculates its expansion metric and compares it with the value contained in the RREQ in order to adjust the value of P using equation (2). The forwarding zone has been implemented using a node's positioning information. This information can be obtained either from a Global Positioning System (GPS) or using the Received Signal Strength (RSS) [6][7]. If a GPS is used then the RREQ should include the positioning information. On other hand, if RSS is used it should be calculated by the intermediate node once it has received the RREQ packet.

III. Performance Evaluation

The Network Simulator 2 (NS-2.34) has been used to compare the proposed approaches. The approach has used the Waypoint mobility model [8]. In this model, a node moves from its current position to a new position by selecting a random direction and a random speed in the range 1 to 5 m/s. Each node will have a different allocated speed from its neighbors. The pause time is 0, which means the nodes are always moving. In this letter two different network scenarios are considered for simulation viz, (1) 1000 x 1000 m^2, (2) 1700 x 1700 m^2. These scenarios evaluate the proposed flooding scheme for increasing node density. The simulation time for both scenarios is 1000 s with a warm up period of 300 s. According to [9], this warm up period has been proved to be suitable to reach a steady-state of the random waypoint mobility model. The used traffic is Constant Bit Rate (CBR) with a packet size of 512 bytes, and a packet rate of 4pck/s. The number of nodes in the network is varied from 50 to 100 nodes in steps of 5, and the nodes' initial positions are chosen randomly. The maximum number of connections among the nodes at any point in time is 50 connections and they start at random times during the warm-up period.

The proposed flooding techniques have been compared with the simple flooding scheme, denoted by S-Flooding, and the probabilistic flooding which is denoted by P-Flooding. The density based flooding with the expansion metric is denoted by E-flooding, the proposed forwarding zone flooding and Hybrid flooding techniques are represented by FZ-Flooding, and H-Flooding respectively. In the P-Flooding, the value of the forwarding probability P is constant and equal to 0.5 as recommended in [2]. In E-Flooding P_i is equal to 0.5, while the value of P_d is 0.15. A wide range of values for P_d has been evaluated and a value of $P_d = 0.15$ is found to provide the best results. This P_d value corroborates the results presented in [10] where the authors stated that in a dense network a low value of forwarding probability is sufficient to achieve high connectivity. In the FZ-Flooding the boundaries are $r_e = 50$ m and $r_b = 220$ m. To prove the validity of the proposed approaches two metrics have been evaluated against an increasing network density (increasing number of nodes in a given area) namely: (a) Packet Delivery Fraction (PDF) is defined as the ratio of packets received successfully by the destination node and gives an idea of the general performance of the network and (b) Normalized Routing Load (NRL) is defined as the number of routing packets transmitted for every data packet sent and evaluates the flooding technique. In the graphs presented below, each point has been generated by averaging out the results of 10 simulations. Confidence intervals of 95 % have also been included in the graphs.

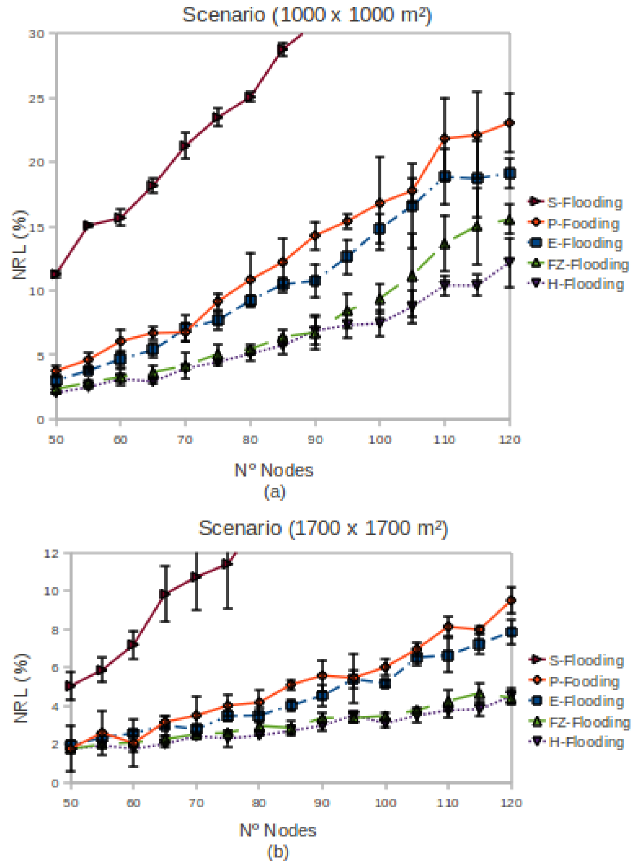

Fig. 3. NRL for increasing node density.

Fig. 3 (a) and (b) show the results obtained for NRL for both the two network scenarios. As it can be seen, all the three proposed approaches namely, the H-Flooding, E-Flooding and FZ-Flooding outperform both the simple and P-Flooding techniques. In general, the E-flooding scheme performs better for higher network densities. The reason being, in certain applications, where the placement (or distribution) of nodes could not be controlled by the user, the density would vary significantly across the network area. The E-Flooding takes advantage of this situation. It has been shown that random Waypoint mobility does not have a uniform distribution of nodes in the network [11]. Moreover, border effects also contribute to this variation in density in the network. On the other hand, in trace-based mobility models the mobility of nodes is influenced by the social relationships of nodes and location preferences [12]. These aspects can make a node's degree in the network more varying compared with that in Random Waypoint mobility model. As a result, our proposed scheme is expected to achieve even better results in real life applications. Note that a reduction of NRL also means a reduction of energy consumption, which is of paramount importance in wireless networks. For the purpose of clarity the PDF results of S- Flooding, P-Flooding and H-Flooding are compared in Fig. 4 (a) and (b).

The results demonstrate the importance of the proposed broadcast schemes on the performance of the reactive routing protocols. When the density of the nodes is the lowest in Fig. 4 (b) the S-Flooding displays similar behavior to that of H-Flooding. Whereas value of P in P-Flooding is inefficient for

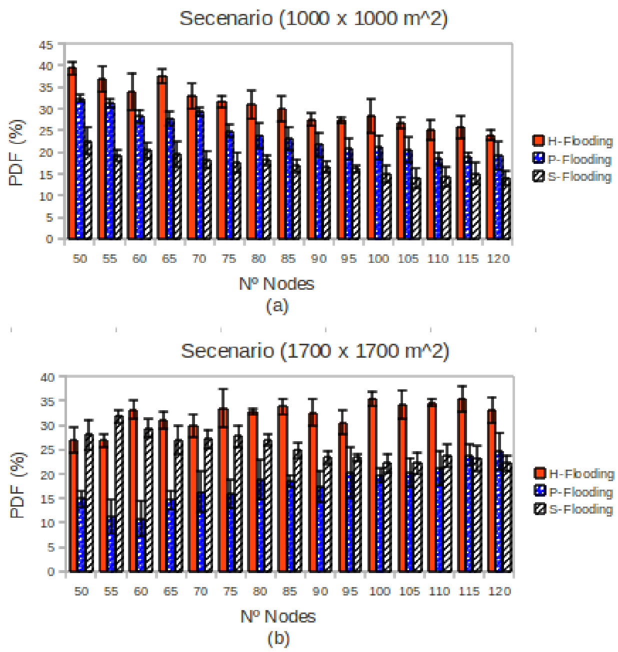

Fig. 4. PDF for increasing node density.

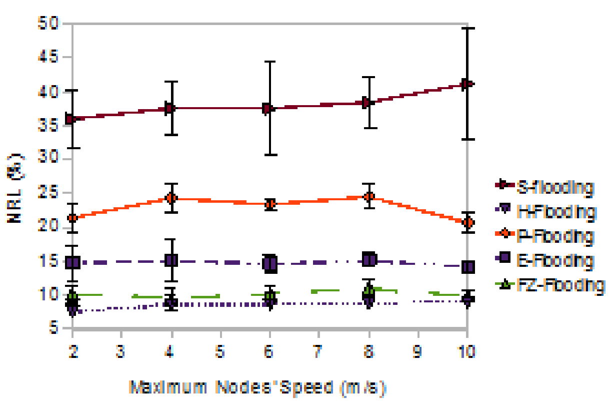

Fig. 5. . NRL results for different maximum nodes' speeds.

low density of nodes.

When the density of nodes is higher, the value of P should be adjusted in order to avoid redundant packets. Since the neighborhood's information is changeable and the changes are strongly dependent on the nodes' speeds, the proposed approaches have also been evaluated under different maximum nodes' speeds. The obtained simulation results are shown in Fig. 5. The number of nodes is 90 (medium density) and the maximum node's speed is 10 m/s. From Fig. 5, it can be seen that the NRL values for the proposed schemes outperform that of the S-Flooding and P-Flooding, for increasing node's maximum speed

IV. Conclusion

The proposed broadcast scheme in this letter has an important role in the performance of routing protocols in Ad Hoc Networks. Simple flooding is clearly inefficient for mobile ad hoc networks. Probabilistic flooding improves the performance of simple flooding to some extent. However, the value of P should be adjusted to the situation of the network. Therefore, a hybrid flooding scheme has been proposed in order to combine the best of probabilistic, neighbor knowledge and area based flooding schemes. The result is a broadcast scheme which adapts its probability to the conditions of the network. In addition it also reduces the overhead caused by the broken links and speeds up the discovery phase by guaranteeing new exploration areas. The obtained simulation results validate the proposed approaches. We are currently participating in a collaborative experimentation to extract real-life traces of mobility models. So, the proposed hybrid scheme will be evaluated using a real trace mobility model in our next phase of research work

References

[1] T. Camp and B. Willian, "Comparison of broadcasting techniques for mobile ad hoc networks," in *Proc. 2002 ACM International Symposium on Mobile Ad Hoc Networking and Computing*, pp. 194-âĂŞ205.

[2] Z. J. Haas, J. Y. Halpern, and L. Li, "Gossip-based ad hoc routing," *IEEE/ACM Trans. Networking*, vol. 14, no. 3, pp. 479-âĂŞ491, June 2006.

[3] S. Park, E. Lee, H. Park, H. Lee, and S. Kim, "Mobile geocasting to support mobile sink groups in wireless sensor networks," *IEEE Commun. Lett.*, vol. 14, no. 10, pp. 939-âĂŞ941, 2010.

[4] W. Peng and X. Lu, "On the reduction of broadcast redundancy in mobile ad hoc networks," in *Proc. 2000 ACM International Symposium on Mobile Ad hoc Networking & Computing*, pp. 129âĂŞ-130.

[5] F. Yu, E. Lee, S. Park, and S. Kim, "A simple location propagation scheme for mobile sink in wireless sensor networks," *IEEE Commun. Lett.*, vol. 14, no. 4, pp. 312-âĂŞ323, 2010.

[6] D. G. Reina, S. L. Toral, P. Johnson, and F. Barrero, "A reliable route selection scheme based on caution zone and nodes' arrival angle," *IEEE Commun. Lett.*, vol. 15, no. 11, pp. 1252-âĂŞ1255, Nov. 2011.

[7] Q. Wang, I. Balasingham, M. Zhang, and X. Huang, "Improving RSS-based ranging in LOS-NLOS scenario using GMMS," *IEEE Commun. Lett.*, vol. 15, no. 10, pp. 1065-âĂŞ1067, 2011.

[8] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc networks research," *Wireless Commun. & Mobile Computing*, vol. 2, no. 5, pp. 483-âĂŞ502, 2002.

[9] J. Yoon, M. Liu, and B. Noble, "Random waypoint considered harmful," in *Proc. 2003 INFOCOM*, vol. 2, pp. 1312-âĂŞ1321.

[10] Y. Sasson, D. Cavin, and A. Shiper, "Probabilistic broadcast for flooding in wireless mobile ad hoc networks," in *Proc. 2003 IEEE Wireless Communications and Networking Conference*, vol. 2, pp. 1124–1130.

[11] W. Navidi and T. Camp, "Stationary distributions for the random waypoint mobility model," *IEEE Trans. Mobile Computing*, vol. 3, no. 1, pp. 99âĂŞ-108, Jan.-Mar. 2004.

[12] C. Boldrini and P. Passarella, "HCMM: modelling spatial and temporal properties of human mobility driven by users' social relationships," *Computer Commun.*, vol. 33, pp. 1056âĂŞ-1074, 2010.