Neighbor Discovery and Selection based on the Management of Priorities in Wireless Ad Hoc Networks

Jose Vicente Sorribes, Jaime Lloret, Lourdes Peñalver
Universitat Politecnica de Valencia, Valencia, Spain
jvsorribes@hotmail.com, jlloret@dcom.upv.es, lourdes@disca.upv.es

***Abstract*—Neighbor discovery can be seen as a crucial point after the wireless ad hoc networks have been deployed. In some practical situations we would like to elect a favourite neighbor to be used for example as a gateway therefore neighbor selection is also required. In this paper, we present NDSP (Neighbor Discovery and Selection Protocol), a randomized approach which handles collision detection to fulfill the neighbor discovery in static environments, and deals with priorities to elect these favourite nodes. We relied on Castalia 3.2 in order to compare the approach with two protocols selected from the literature, modified to include neighbor selection: the NS-PRR (Neighbor Selection PRR), and the NS-Hello protocol (Neighbor Selection Hello). We conclude that the NDSP outperforms both reference protocols in terms the time and the energy consumption, and the number of packets sent in both one-hop and multi-hop environments. Furthermore, the proposal achieves to work following more realistic assumptions.**

***Index Terms*—wireless ad hoc networks, wireless sensor networks, neighbor discovery, neighbor selection, randomized, collision detection, priority.**

I. INTRODUCTION

Neighbor discovery techniques must be provided for wireless ad hoc networks as they do not have a communication infrastructure, and the neighbors are unknown [1][2]. However, since some nodes require to forward information in a multi-hop way, every node must have routing capabilities [3][4], and they must be able to self-configure to set up a communications infrastructure [5][6].

This type of networks can be either static [7], or mobile [8]. In the randomized neighbor discovery algorithms each node begins to transmit at a random time. On the other hand, the deterministic protocols follow a schedule.

Moreover, in wireless ad hoc networks neighbor selection methods are necessary to discover which neighbor the information must be sent in a one hop to reach a destination. In this work we center on neighbor discovery and neighbor selection achieved by priority management in static wireless ad hoc networks.

The importance of our work is that it improves the reference protocols, especially in the neighbor discovery phase, since it knows when to terminate the neighbor discovery, the neighbors are discovered with probability 1. Furthermore, it does not need to know the number of nodes in the network, and allows the nodes to start transmissions at different time instants. Moreover, after finishing the protocol, all the nodes know their favourite nodes and all the nodes know whether they are favourite or not.

The main contributions of this paper are: (i) NDSP (Neighbor Discovery and Selection Protocol), a randomized approach based on Hello protocol and collision detection. (ii) Analytical model of NDSP. (iii) Implementation of the proposal, NS-Hello (extension of Hello [9] for neighbor selection) and NS-PRR (extension of PRR [7] for neighbor selection) using Castalia 3.2 [10] for comparison purposes.

The outline of the paper is as follows: A brief related work is included in Section 2. Our proposal, assumptions and model are presented in Section 3, the simulation scenario and the simulation results are shown and discussed in Section 4. Finally, some concluding remarks are made in Section 5.

II. RELATED WORK

Among the neighbor discovery protocols from the literature, in [7] PRR is an energy efficient protocol. In [9] two Hello protocols are proposed. In [11] KPND is proposed, a fast and efficient protocol for highly dynamic scenarios. In [12] a fast protocol is introduced for MTC (Machine-type communication). In [13] an approach appropriate for highly dynamic resource constrained MANETs is presented. The authors in [14] propose ND HC, a cross-layer algorithm for large networks. In [15], an algorithm in which the nodes are considered as intelligent agents, is presented. RCI-SBA [16] is an energy efficient neighbor discovery protocol that integrates radar and communication. In [3] a fast and energy efficient approach that makes use of social information recognition for MANETs is proposed. Finally, in [4] a fast and energy efficient approach for MSNs (Mobile Sensor Networks) is introduced.

There are several neighbor selection strategies in the literature. In [17] the nodes select their neighbors so that they minimize their energy consumption. In [5] the authors proposed a fast and suitable mechanism for group-based WSNs. In [18] an algorithm focusing on highly dynamic urban mobility is introduced. In [19] an approach that allows each node to forward the message only to a smaller subset of neighbors is introduced. In [20] an approach that uses intelligent machine learning for MANETs, is proposed. The authors in [21] propose a lightweight artificial neural network (AF) mechanism for resource-constrained WSNs.

In [22] energy efficient algorithms for routing in WSNs are analyzed. In [23] and [24] energy-efficient protocols for selecting CHs (Cluster Heads) in WSNs are presented. Finally, [25] introduces a protocol to select trustworthy CHs based on power consumption in WSNs.

III. Neighbor discovery and selection protocol

In this section, we proceed to present the NDSP proposal.

A. Assumptions

The time is slotted in rounds, and the nodes cannot move. Each node holds a unique identifier and a priority (a number). The nodes are placed in a random way in a certain area, synchronization is required in slot boundaries, and the number of nodes remains unknown by any node. Each node holds a radio transceiver with a limited transmission range (half-duplex). Each node holds a neighbor table to save identifiers and priorities, collisions may appear, the nodes can detect collisions when they are listening and they can detect energy and termination. The nodes are allowed to start transmitting at different time moments.

B. Model

The NDSP proposal combines neighbor discovery and neighbor selection through priority management in order to achieve to discover the neighbors and mark the favourite nodes.

According to Figure 1, the time is slotted in rounds and there are two sub-slots in each round. The first sub-slot of width ω is used to exchange discovery messages, while the second sub-slot of width ω_f is used to exchange the feedbacks. These two times ω and ω_f are fixed (the same for all the rounds).

Each node holds a priority in its memory, whose initial value is predetermined and fixed before the deployment.

The goodness of the favourite nodes selected by the proposal depends on the predetermined priority. This means that the higher the priority the better features will present the node to be selected as favourite node.

Furthermore, the proposal finishes when all the neighbors have been discovered, every node knows its favourite node, and each node knows whether it is a favourite or not.

In this way, two things take place, i.e., each node knows who its single favourite is, and each node which is favourite knows that it is.

Say a network composed of 3 nodes, A, B and C. A's priority is higher than that for C. Suppose A is favourite of B but not of C. Then A considers itself as favourite.

As shown in Figure 1 and the flow diagram in Figure 2, in the first sub-slot each node transmits a single BROADCAST packet which contains its identifier and priority beginning in a random time $t_i \in [0, \omega - \tau]$ during τ, and keeps listening for a total duration of $\omega - \tau$. In this first sub-slot, all the nodes perform a collision detection process during the periods of time in which they are listening.

In the second sub-slot, which is used for the feedbacks, all the nodes are scheduled to send a serial of feedback

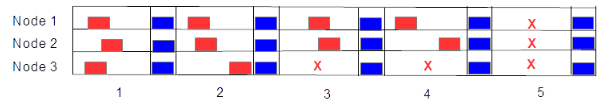

Fig. 1. NDSP (timeline).

packets (one feedback packet after another) indicating which nodes transmitted successfully. The second sub-slot consists of *length_serial* possible feedback packets.

As soon as the *jth* feedback packet is scheduled to be sent in the second sub-slot, the nodes whose identifier *ident* is different from *j* will send a single feedback packet if node *j* transmitted successfully, while the node whose *ident* is equal to *j* will listen to the channel. Otherwise, that is, if the BROADCAST of node *j* collided the node *ident* different from *j* will not send any feedback packet.

Furthermore, if *j* transmitted successfully, that is, a collision was not detected for node *j*, the rest of the nodes that received its BROADCAST store the identifier *j* and the priority *prio*, that are available in the BROADCAST, in their neighbor tables. Otherwise, no information is stored in the neighbor tables.

The nodes with *ident* equal to *j* listen to the channel at that moment in the second sub-slot and if energy is detected by node *j*, i.e., a feedback packet is in the channel, it will shift to S state, it will not contend from then on in the first sub-slots and it will remain listening. This is signalled as a red X mark in Figure 1. However, it will send the feedback packets when required in the second sub-slot. Otherwise, it will keep contending in the following rounds choosing a new t_i in the first sub-slot. When *j* reaches the *length serial* a new round begins for the remaining nodes.

Notice that the feedback packets are much smaller than the BROADCASTs.

The NDSP includes a termination detection mechanism for the neighbor discovery, in which the protocol finishes the discovery when every node achieved to transmit successfully in previous rounds. This is detected by the nodes when in a round there is no signal in the channel during the first sub-slot, which means that every node is in the S state.

As soon as the termination is detected, the neighbor selection process begins, all the nodes proceed to elect their favourite nodes by using the priorities stored in their neighbor tables and choosing the node *ident* with the highest priority *prio*. If several nodes in the neighbor table have the same highest priority, the nodes choose that for the lower identifier. Then, a slot of width w_f begins in which the nodes tell the other nodes one after another if they are the favourites by sending feedback packets, in a similar way to the feedback mechanism for the neighbor discovery process.

When the *jth* feedback packet is scheduled to be sent, the node with *ident* different from *j* sends the feedback packet if node *j* is a favourite, while the node with *ident* equal to *j* listens to the channel. If node *j* detects energy, then the node knows that it is a favourite and internally marks the node as favourite. This process will follow until j reaches *length serial* (the maximum amount of feedback packets). Furthermore, each node knows its favourite node by checking which node in its neighbor table has its highest priority.

Algorithm 1 shows more deeply the operation of the proposal.

Algorithm 1 NDSP

Require: τ time a node is transmitting, ω (a fixed first sub-slot duration), ω_f (a fixed second sub-slot duration), *ident* (identifier), *prio* the priority

termination = false
while not termination **do**
  Choose randomly $ti \in [0, \omega - \tau]$
  Keep listening until t_i.
  Send BROADCAST(ident,prio) beginning in t_i during τ.
  Keep listening until ω.
  for every j **do**
    if j == ident **then**
      Listen to the channel.
      Perform energy detection.
    else
      if node j transmitted successfully **then**
        Send feedback packet.
        Update neighbor table with identifier j and priority *prio* contained in the BROADCAST from node j.
      end if
    end if
    if j detected energy **then**
      Node j in state S from now on and keeps listening until the end of the neighbor discovery, although it will send feedback packets when necessary in the following rounds.
    else
      New round. Node j keeps contending in the following round.
    end if
  end for
  if no BROADCAST was received **then**
    termination = true
  end if
end while
for every j **do**
  Elect favourite from the neighbor table.
end for
for every j **do**
  if j == ident **then**
    Listen to the channel.
    Perform energy detection.
  else
    if node j is favourite **then**
      Send feedback packet.
    end if
  end if
  if j detected energy **then**
    Node j marked as favourite.
  end if
end for

Next we take into account a one-hop scenario and obtain the following equations for the selection mechanism. Equation 1 shows the time it takes to finish in seconds, being τ_f the time a node is transmitting a feedback packet. We conclude that the time consumption is linear $O(N)$.

$$T = N \cdot \tau_f \tag{1}$$

Equation 2 shows the average energy consumed per node in Joules, being E_{tx} the energy consumed by a single node when transmits per second, and E_l the energy consumed by a single node when listens per second.

$$E = \frac{1}{N}\tau_f \cdot [N \cdot E_{tx} + N \cdot (N-1) \cdot E_l] = \tau_f \cdot [E_{tx} + (N-1) \cdot E_l] \tag{2}$$

As for the packets sent, it is shown in equation 3.

$$P_{sent} = N \tag{3}$$

IV. Performance Results

Next we present the simulation results of the NDSP compared with NS-Hello and NS-PRR.

A. Simulation scenario

For performance comparison we relied on Castalia 3.2 simulator [10]. Two deployment areas have been set, i.e., one-hop (10mx10m) and also multi-hop (100mx100m) and the N nodes are arranged in MxM grids. The collision model parameter of Castalia 3.2 takes the value 2, i.e., additive interference model. A width of $\omega = N \cdot \tau$ is set for the first sub-slot in NDSP and for the round duration of NS-Hello. As for the NS-PRR we set a round duration of τ. We set τ, the time in which a node is transmitting a BROADCAST, to $0.07s$. For NSDP a second sub-slot has been fixed to $\omega_f = N \cdot \tau_f$. Moreover, the neighbor selection mechanism uses an additional slot of width $\omega = N \cdot \tau_f$ for all the protocols under test, being $\tau_f = 0.000392s$. The radio model used is ZigBee (CC2420), the transmission power has been set to - $5dBm$, the packet rate to $5 packet/s$, the BROADCAST packet size to $2500 bytes$ and the feedback packet size to $14 bytes$. The number of rounds for NS-PRR have been set to $10 \cdot N$ in the one-hop case and $6 \cdot N$ in the multi-hop case. For the NS-Hello we set $0.5 \cdot N$ rounds in the one-hop scenario and $0.25 \cdot N$ rounds in the multi-hop setting.

First, the parameter N is set for different values. Then, for each value of N, the number of discovered neighbors and other metrics have been obtained. Finally, we show the results for the different metrics against the number of discovered neighbors.

The number of discovered neighbors is defined as the amount of neighbors that are discovered by a node in the neighbor discovery phase.

B. Simulation results

Next, the simulation results for the 3 protocols under test are shown and discussed.

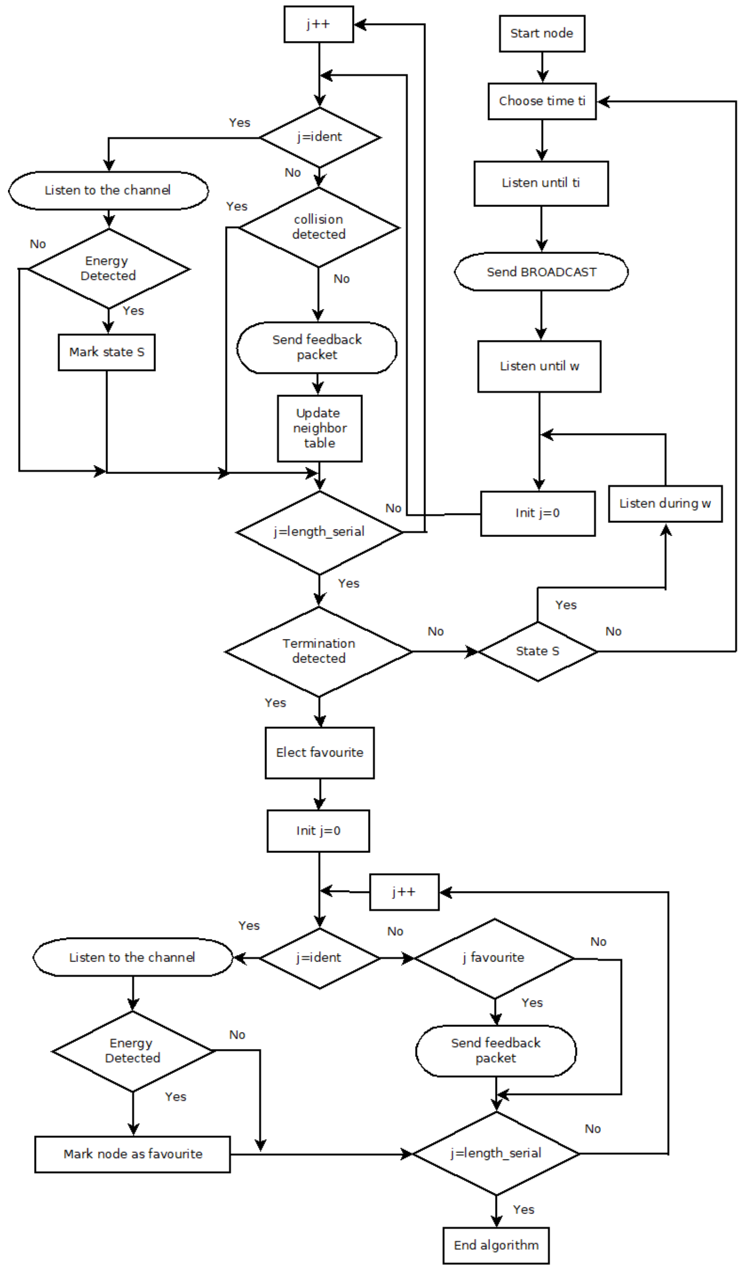

Fig. 2. NDSP flow diagram.

1) Time consumption: According to Figure 3 and Figure 4, the NDSP proposal outperforms both reference protocols in both environments, followed by NS-PRR and finally NS-Hello is the worst. The time consumption increases as the number of discovered neighbors grows, since for NDSP as the number of discoveries gets bigger more time is necessary to discover all the neighbors and for NS-Hello and NS-PRR a number of rounds which depends on N is fixed thus the time consumption increases as the number of discovered neighbors grows.

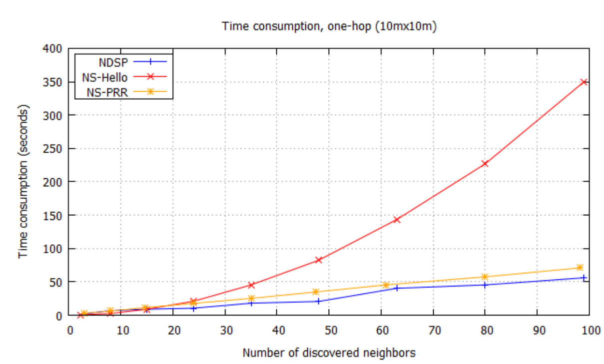

Fig. 3. Time consumption (one-hop).

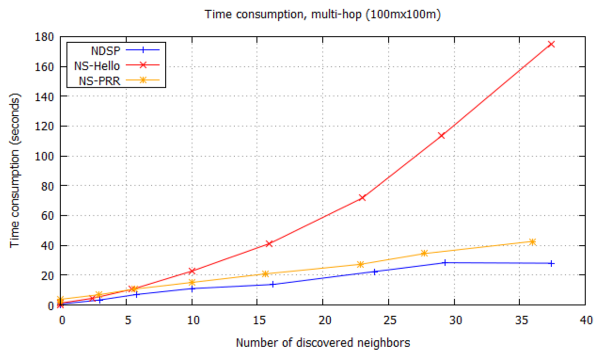

Fig. 4. Time consumption (multi-hop).

2) Energy consumption: As shown in Figure 5 and Figure 6, again the NDSP proposal improves both reference protocols in both environments, followed by NS-PRR and the NS-Hello is the worst. Again, for the 3 protocols the energy consumption increases as the number of discovered neighbors gets bigger for the same reason explained for the time consumption.

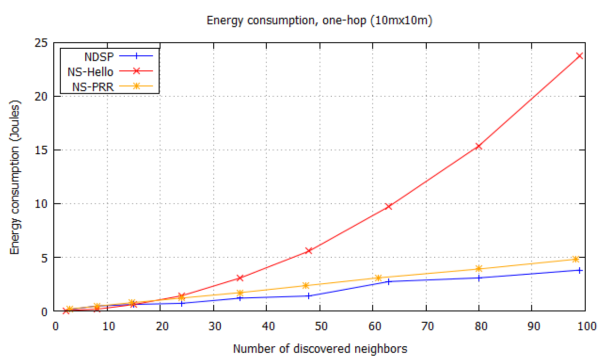

Fig. 5. Energy consumption (one-hop).

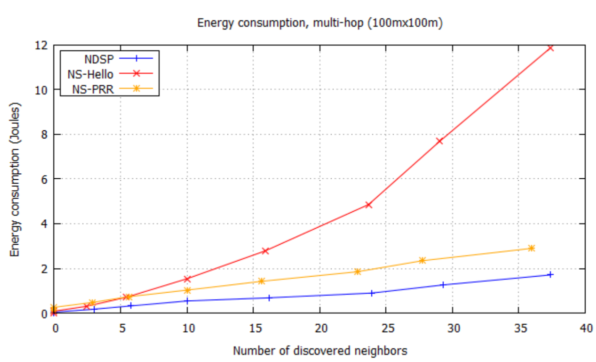

Fig. 6. Energy consumption (multi-hop).

3) Number of packets sent: As shown in Figure 7 and Figure 8, NDSP improves both reference protocols in both environments and NS-Hello is the worst. The packets sent increases as the number of discovered neighbors gets bigger.

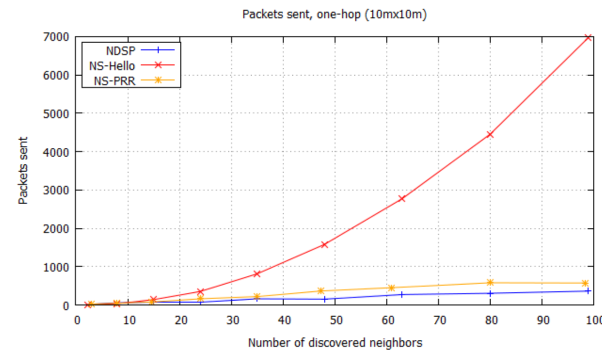

Fig. 7. Packets sent (one-hop).

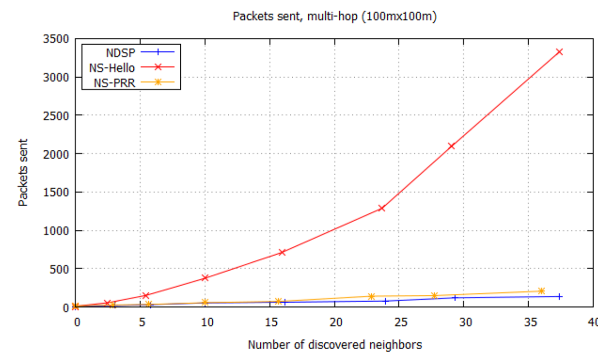

Fig. 8. Packets sent (multi-hop).

V. Conclusion

We addressed a study of neighbor discovery and neighbor selection mechanisms for static wireless ad hoc environments coping with the existence of collisions.

For this purpose, two existing protocols have been selected, i.e. Hello and PRR, and modified them to perform both neighbor discovery and neighbor selection (NS-Hello and NS-PRR) and used as reference to compare with NDSP our randomized handshake-based approach.

Furthermore, we found through simulations through Castalia 3.2 that NDSP achieves better results than the reference protocols in terms of the time and the energy consumption, and the packets sent.

Moreover, this improvement is due to the neighbor discovery scheme used, i.e., the priority management does not affect the performance since the same selection mechanism regarding priorities is performed in NDSP, NS-Hello and NS-PRR. However, the overhead introduced by priority management is low, which means an improvement over past methods.

As stated above, the proposal removes the difficulty of reference protocols since, it follows more realistic assumptions.

The NDSP can be applied in wireless sensor networks in which favourite nodes are required to allow external availability of data (gateway) in further operations.

As future directions, we would like to develop and evaluate energy-aware neighbor discovery and selection protocols for static environments, which allow its use in mobile networks.

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