Neighbor Discovery Analysis in Wireless Sensor Networks

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ABSTRACT
In wireless sensor networks, hello protocols for neighbor discovery are a basic service offered by the networking stack. However, their study usually rely on rather simplistic models. In this paper we study the impact of radio interferences on neighbor discovery and we introduce an analytical model to estimate the average number of neighbors that a node may expect to discover in his neighborhood.

Categories and Subject Descriptors
C.2.1 [Computer Communication Networks]: Wireless communications

General Terms
Performance, Design

Keywords
Wireless networks, Neighbor discovery, Stochastic geometry, Performance analysis

1. INTRODUCTION
Wireless sensor networks are communication systems where the infrastructure is dynamically created and maintained. To enable communications, hosts cooperate together to provide several complex services like routing or data gathering. All these high level services usually rely on a neighbor discovery protocol. During the process of neighbor discovery, a node tries to find out which other nodes are within its transmission range. To accomplish this discovery, a node broadcasts periodically a hello packet to inform the nearby nodes of its presence. This periodic exchange of hello messages is used to create and maintain a local neighborhood table, which will be used by higher level protocols. Most of the studies made on hello protocols use simplistic models which do not take into account the specificities of radio communications, like the radio interferences. These interferences increase the collisions and decrease the network’s capacity. Taking into account these interferences is thus important, in particular for the dimensioning of hello protocols.

2. MODELS AND ASSUMPTIONS
We assume a dense network with a large number of nodes. These nodes are uniformly and independently distributed in a vast two-dimensional geographical region according to a Poisson point process of constant intensity \( \lambda \). We consider a path-loss propagation model. This model results into a perfect circular coverage area around each node with a maximal radius : \( R(P_i) = \left( \frac{P_i}{\gamma} \right)^{\frac{1}{\beta}} \), where \( \beta \) is the path-loss exponent, \( P_i \) is the transmission power and \( \theta \) is the threshold for a correct signal decoding. In this study, we consider two sensing models based on this path-loss attenuation : a Boolean model, where simultaneous communications of two or several nodes within reach communication yields to a collision, and a more realistic one, called SINR model, based on the signal to interference ratio. With the SINR model, a node \( y \) can receive a signal from a node \( x \) if the ratio of power it receives from \( x \) to the total power received from all other nodes is above a given threshold. This model is given by [2]:

\[
N + \gamma \sum_{k \neq (x,y)} \frac{P_k}{d(x,y)^{\beta}} \geq \theta \tag{1}
\]

where \( N \) is the power of the thermal background noise and \( \theta \) is the signal to noise ratio required for successful signal decoding. \( \gamma \) depends on the orthogonality between the radio resources (codes or frequencies) used during simultaneous transmissions. In this study we suppose that \( \gamma = 1 \).

Figure 1: The random hello protocol.

The hello protocol used throughout this study, is a random protocol inspired by Aloha [1] as depicted on figure 1. Each node can be in one of the following three states: listening (during \( w - \delta \) ), talking (during \( \delta \) ) or sleeping (during \( s \) ). These states are performed inside a frame, \( F \), of size \( w + s \). In each occurrence of \( F \), a node picks randomly an instant \( t_w \) to position the frame \( F \), such that \( t_w \in [0, w] \). Then, a node picks an instant \( t_s \), such that \( t_s \in [t_w, t_w + w - \delta] \).
The hello message is then transmitted at $t_i$ with a duration of $\delta$. The medium access probability is thus: $\rho = \frac{1}{\beta}$. 

3. IMPACT OF INTERFERENCES

During the process of neighbor discovery, the identity of a discovered node is added to the local neighborhood tables of the nodes which have received the hello packet. From these tables, we can generate the corresponding graph of connectivity. In figure 2, we present the graphs of connectivity obtained after one occurrence of the frame $F$, and corresponding to the Boolean and SINR sensing model.

![Figure 2: Graphs of connectivity for different sensing models. ($w = 200$, $\delta = 10$, $\lambda = 0.0035$, $P_t = 10^5$, $\theta = 5$, $\beta = 3$, $N = 1$, $s = 0$).](image)

Given that the SINR sensing model takes into account the interferences with more accuracy, we can observe that the number of discovered nodes is lower with regard to the Boolean model. The obtained graph is then disconnected with the existence of several isolated nodes. By running the hello protocol a little longer, we found that, in presence of interferences, the average number of discovered nodes remains lower than the maximal number of neighbors within reach communications. This result suggests clearly that there is a given upper-bound, $r(P_t)$, lower than the maximal sensing area $R(P_t)$, and beyond which nodes are not discovered.

4. AN HYBRID MODEL

Considering the SINR sensing model, when a node $x$ transmits a hello message, the node $y$ can decode this message only if the signal-to-noise ratio is above a given threshold $\theta$. From the equation 1, the distance $d(x, y)$ has to satisfy the following condition: $d(x, y) \leq \left(\frac{P_t}{\theta(Ns + \rho)}\right)^{\frac{1}{2}}$, where $I$ is the shot noise and represents the total power received from all other nodes. To compute $I$, we consider a node $i$ and $R(P_t)$ its maximal sensing area in absence of interferences. We suppose an infinite plan around this node and we decompose the interferences in two parts: the internal interferences, $I_{in}$, and the external interferences, $I_{out}$. $I_{in}$ corresponds to the interferences stemming from nodes localized inside the disc of center $i$ and radius $R(P_t)$. $I_{out}$ corresponds to the interferences stemming from nodes which are located outside this disc. The average number of nodes localized at distance almost $r$ from a given node is equal to $2\pi r \lambda$. So, to calculate $I_{out}$, we integrate the previous expression as follows: 

$$I_{out} = \int_{R(P_t)}^{\infty} (2\pi r \lambda)(P_t r^{-\beta}) \, dr = \frac{2\pi \lambda}{\beta - 2} \rho P_t R(P_t)^{2-\beta}$$

where $\rho$ is the medium access probability. For $I_{in}$, no closed formula is available and the integral that we consider diverges for small values of $r$.

For this reason, we define an hybrid model which combines the SINR model for the external interferences and the Boolean model for the internal ones. As we only consider a subset of the interfering nodes, the global interferences are larger than $I_{out}$. The external interferences can be seen as being a lower-bound for the global interferences. By taking into account only these external interferences, we can compute an upper-bound on the distance $d(x, y)$ as follows:

$$r(P_t) = d(x, y) \leq \left(\frac{P_t}{\theta(Ns + 2\pi \lambda \rho \ P_t R(P_t)^{2-\beta})}\right)^{\frac{1}{2}}$$

We simulate our random hello protocol for different sizes of $w$, with $s = 0$, and during one occurrence of $F$. For every $w$, we compute the average distance of the most remote neighbor who was discovered. We compare this simulation value with the analytical value of $r(P_t)$.

![Figure 3: Average distance of the most remote discovered neighbor. ($\delta = 10$, $\lambda = 0.0035$, $\theta = 5$, $\beta = 3$, $N = 1$, $P_t = 10^5$, $s = 0$)](image)

As shown in the figure 3, the more $w$ increases, the more the average distance of the most remote discovered nodes tends towards $r(P_t)$. On the other hand, for low values of $w$ the internal interferences increase, and as a consequence the probability of collision also increases. In that case, the mean distance of the most remote neighbors is lower than $r(P_t)$. The use of our upper-bound, $r(P_t)$, is thus more accurate, than using $R(P_t)$, for the estimation of the average number of neighbors within transmission range. This estimation can be very useful to tune our hello protocol, as we know the average number of nodes we must consider for collisions.

5. CONCLUSIONS

In this paper, we analyzed the impact of interferences on neighbor discovery and we introduced an hybrid model allowing to estimate the average number of neighbors that a node may expect to discover. This model may be very useful in particular for the dimensioning of hello protocols. Several perspectives remain open to investigations. We want to adapt our analysis to a probabilistic radio propagation model. Finally, we wish to study the impact of node mobility on neighbor discovery.

6. REFERENCES
