



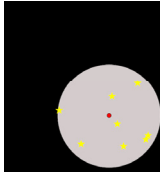
A Practical Compressed Neighbor Discovery Scheme for MANETs

Jun Luo, Lei Zhang, Dongning Guo
Northwestern University

Introduction

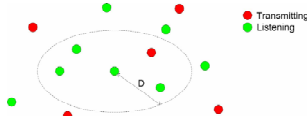
How to Discover Neighbors?

- Query node emits beacon;
- Neighbors illuminated;
- Simultaneous and Synchronized response;



Random-Access Discovery

- [McGlynn and Borbash '01]: birthday protocols;
- [Vasudevan, Kurose and Towsley '05], [Zhang '05]: directional antenna neighbor discovery;
- [Borbash, Empremides and McGlynn '07]: slotted random transmission and reception.

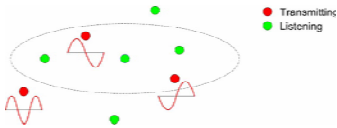


It induces a large amount of overhead because:

- Many repeated transmissions of the identity information are needed to resolve collision;
- Additional redundancy including synchronization and parity check bits are needed for reliable communication in presence of noise and fading.

Multisense Detection

- [Angelosante, Biglieri and Lops '07]: multi-user detection;
- [Lin and Lim '04]: eigenvalue decomposition and subspace projection.



Coherent detection is impractical in MANETs' scenario.

A Simpler Scheme: Based on Group Testing

- [Luo and Guo '08]: noise free case;
- [Luo and Guo '09]: Rayleigh fading without path-loss;

We need to design a **simple, efficient** neighbor discovery scheme for MANETs with fairly realistic propagation model.

Channel and Network Model

Linear System Model

- Many network interfaces uniformly distributed on a disk, but only a few around the query node (node 0).
- The binary vector $B = [B_1, \dots, B_n]^T$ denotes neighborhood of node 0, where $B_i = 1$ if node i is a neighbor, and $B_i = 0$ otherwise. B_n is a Bernoulli random variable with mean c/N , where c is the average number of neighbors of node 0.
- S_n denotes the $M \times 1$ signature transmitted by node n upon receipt of the probe signal. Each element is a Bernoulli random variable with mean q .
- U_n denotes the complex-valued gain of the wireless link between node 0 and neighbor n .
- W is an $M \times 1$ vector consisting of independent unit circularly symmetric complex Gaussian random variables.
- The signal received by the query node is

$$Y = \sqrt{\gamma} \sum_{n=1}^N S_n U_n B_n + W$$

where γ denotes the SNR.

Propagation Model and Neighborhood

- The gain of the channel between a pair of nodes of distance r is given by $Gr^{-\alpha}$.
- A node is defined as a neighbor of node 0 if it receives the probe signal at power no less than a certain threshold, i.e., neighbors satisfy $Gr^{-\alpha} \geq \eta^2$ for some fixed η .
- The pdf of $|U_n|$ of neighbor nodes is

$$p_{|U|}(u) = \begin{cases} \frac{4}{\alpha} u^{-4/\alpha-1} \eta^{4/\alpha}, & u \geq \eta, \\ 0, & \text{otherwise.} \end{cases}$$

which does not depend on the fading statistics at all.

- The average number of neighbors of node 0 in case of Rayleigh fading is

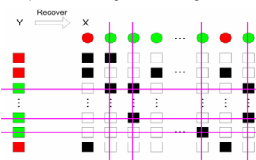
$$\frac{2}{\alpha} \lambda \pi \eta^{-4/\alpha} \Gamma\left(\frac{2}{\alpha}\right)$$

where λ is the node density and $\Gamma(\cdot)$ is the Gamma function.

Compressed Neighbor Discovery

A First Algorithm Based on Group Testing

- An elimination process as in group testing is used for neighbor discovery: for each time slot m , if $|Y_m| < T$, all nodes who would have sent a pulse during that slot, i.e., each node n with $S_{nm} = 1$ would be eliminated. Those nodes which survive the whole process are regarded as neighbors.

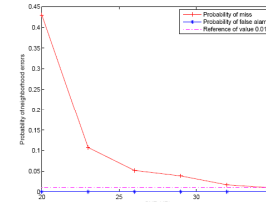


- There are two types of errors:

- Miss: a neighbor is eliminated by the process;
- False alarm: a non-neighbor survives the process.

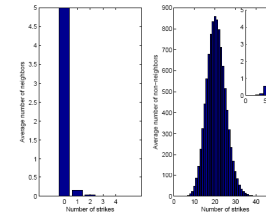
- Simulation result under the remaining parameters $N = 10000, c = 5, M = 1500, T = 1.0, \alpha = 3, q = 0.0247$ shows that

- No false alarms are registered;
- The probability of miss decays with the SNR and drops to about 0.01 at 35 dB.
- If the SNR is 23 dB or lower, the error probability is greater than 0.1, which is **unacceptable** for most applications.



Improved Algorithm

- In order to find out the main causes of the misses, for each node, we record the number of slots which point to its elimination (called strikes). We plot the average number of nodes (out of 10,000 total) which received 0, 1, 2... strikes separately for neighbors and non-neighbors.



- Improved Algorithm

- Instead of eliminating a node as soon as it receives a strike, we require that it be eliminated only if it receives at least 2 strikes.

- For a practical system, false alarms are potentially more detrimental in network reliability than misses, we need to tailor the parameters to control the probability of false alarm under a certain level and in the meanwhile minimizes the probability of miss. An upper bound for the probability of false alarm $P_{f,ub}$ is

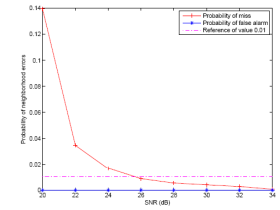
$$N e^{-Mq\Phi(T)} \left(e^{c\eta^2/T} \right) \left(1 + \frac{2MqT^2}{\alpha\eta^2\gamma} e^{c\Phi(T)} + Mq\Phi(T) e^{c\Phi(T)} \right)$$

so for fixed L, γ, p_0, T , to minimize the probability of miss, one can solve the following optimization problem:

$$\begin{aligned} \min_{M,q} & Mq \\ \text{s.t.} & P_{f,ub} \leq p_0, \quad 0 < M \leq L, \quad 0 < q < 1 \end{aligned}$$

- The numerical result for improved algorithm by using the same parameters shows that

- No false alarms are registered;
- The probability of miss is lower than 0.01 with SNR higher than 26 dB.



Comparison with Random-Access Scheme

Comparison with the "Birthday" Algorithm

- In our proposed algorithm, 1500-bit signatures are used and SNR is 30 dB to make the probability of error no greater than 0.004. Suppose transmission of each bit takes one slot.
- In random-access discovery scheme, to achieve a probability of error less than 0.004, it needs at least 91 contention periods each of which takes at least 14 bits. So the total time expense is 1274 slots without taking into account additional overhead such as preamble and parity check bits.

Comparison with IEEE 802.11g

- In IEEE 802.11g ad hoc mode, for the random access discovery scheme, one contention period has to cover the transmission time for one probe response frame, which takes about 850 us. So the neighbor discovery overhead is at least $850 \mu\text{s} \times 91 \approx 77.4 \text{ ms}$.
- For the compressed neighbor discovery scheme, a conservative choice of the chip time is 25 us, which leads to a total overhead $25 \mu\text{s} \times 1500 = 37.5 \text{ ms}$. This represents more than 50% reduction in terms of neighbor discovery overhead.

Conclusion

- A simple, efficient and practical neighbor discovery scheme is proposed for ad hoc networks. Comparison with the conventional random access discovery schemes shows that the proposed scheme achieves faster neighbor discovery with high accuracy.
- Although we only consider neighbor discovery at one particular node, it can be extended to the case where all nodes discover their respective neighborhoods simultaneously.