Distributed Neighbor Discovery in Ad Hoc Networks Using Directional Antennas

Rully Adrian Santosa, Bu-Sung Lee, Chai Kiat Yeo and Teck Meng Lim

School of Computer Engineering, Nanyang Technological University, Singapore

Motivation

- Design algorithm for neighbor discovery in ad-hoc network
  - Directional antennas
  - Distributed algorithm
- Minimize number of neighbors involved in the discovery process
- Maximize number of one hop neighbors discovered

Directional vs. Omnidirectional antennas

Directional:

- – Minimizes interference
- – Transmission range extended
  - Assume range twice the size
- – More nodes can be reached in one hop

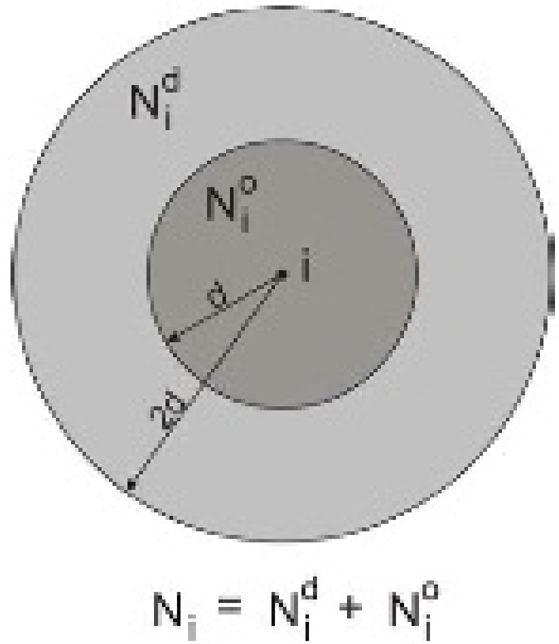

Figure 1. Sets of neighbors of node i.

Algorithm 1 Node x joining the system

Let N_x be the neighbor list of node x
$N_x \leftarrow \emptyset$
broadcast request message using omnidirectional transmission to initiate neighbor discovery process
wait for response messages containing neighbor information from the representative nodes
for all neighbor information R contained in the received response messages **do**
    $N_x \leftarrow N_x \cup R$
end for

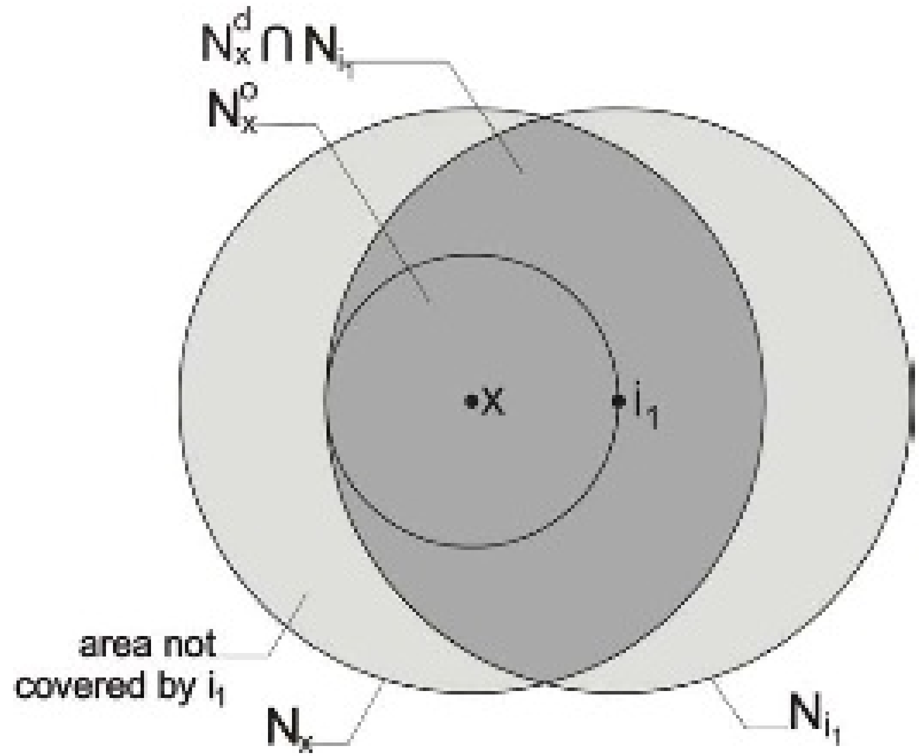

Figure 2. Worst case scenario in choosing the first representative node, i_1.

Representative Nodes

The nodes included in set S should be chosen such that

- the union of the directional transmission range $2d$ of all nodes in S covers the directional transmission range $2d$ of node x, i.e.

$$N_x \subset \bigcup_{i \in S} N_i$$

- the number of nodes in S is minimized.
  Intuitively, the best case for the number of nodes in S is 1, i.e. when the representative node is located extremely close to x.

Representative Node Heuristic

- Select node closest to x
- If there is a tie, select first node in cw direction starting north of x
- Repeat selection till there are no new neighbors to be added
- This heuristic guarantees to cover 68.4% of directional area

Algorithm 2 Each node i in the omnidirectional transmission range of x

receive broadcast request message from x
Let N_i be the neighbor list of node i
$N_i \leftarrow N_i \cup \{x\}$
$W \leftarrow (N_i \cup \{i\}) - \{x\}$
for all $j \in W$ **do**
    if $distance(x, j) > 2d$ **then**
        $W \leftarrow W - \{j\}$
    end if
end for
$Z \leftarrow W$
sort all $j \in W$ in ascending order based on $distance(x, j)$, then based on $angle(x, j)$
for all $j \in W$ **do**
    if $j = i$ **then**
        exit for
    end if
    $Z \leftarrow Z - \{j\}$
    for all $k \in W, k \neq j$ **do**
        if $distance(j, k) <= 2d$ **then**
            $Z \leftarrow Z - \{k\}$
        end if
    end for
end for
if $Z \neq \emptyset$ **then**
    send Z to x using directional transmission
else
    do nothing
end if

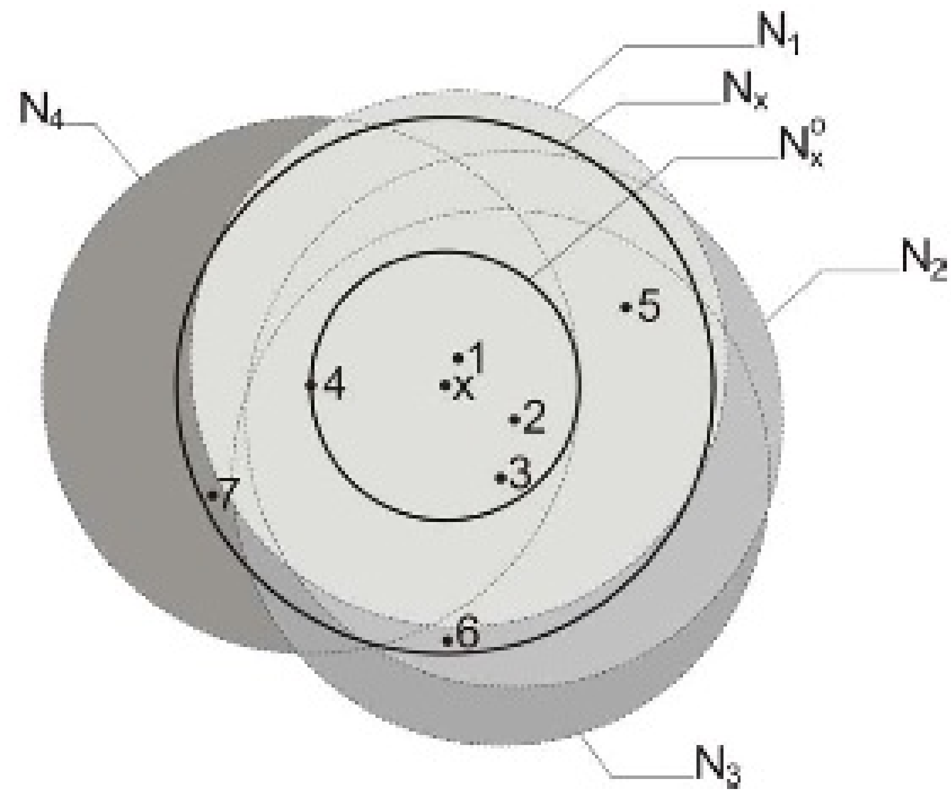

Figure 3. Scenario of a new node x starting the neighbor discovery process.

Analysis

- Number of new neighbors discovered depends on the number and position of neighbors in the omnidirectional area
- Use Monte Carlo technique to calculate C(n) - Expected coverage

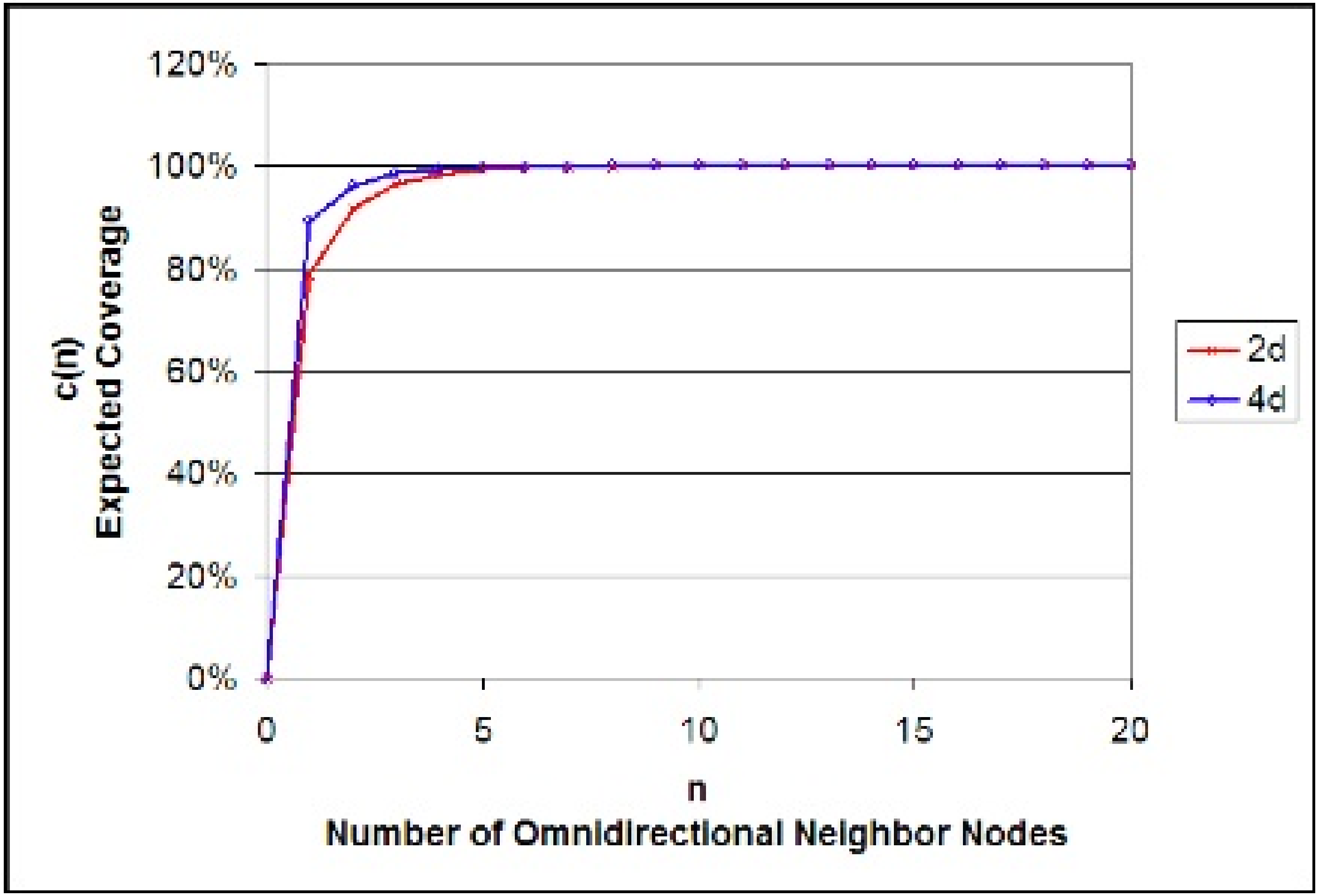

Figure 4. Expected coverage $c(n)$ against the number of neighbor nodes inside the omnidirectional transmission range.

Expected coverage

- Omnidirectional range

$$\lambda = \rho \pi d^2$$

- Probability finding n nodes in omnidirectional area

$$p(n) = \frac{\lambda^n e^{-\lambda}}{n!}$$

- Expected coverage

$$E[c(n)] = \sum_{k=0}^{\infty} p(k) c(k)$$

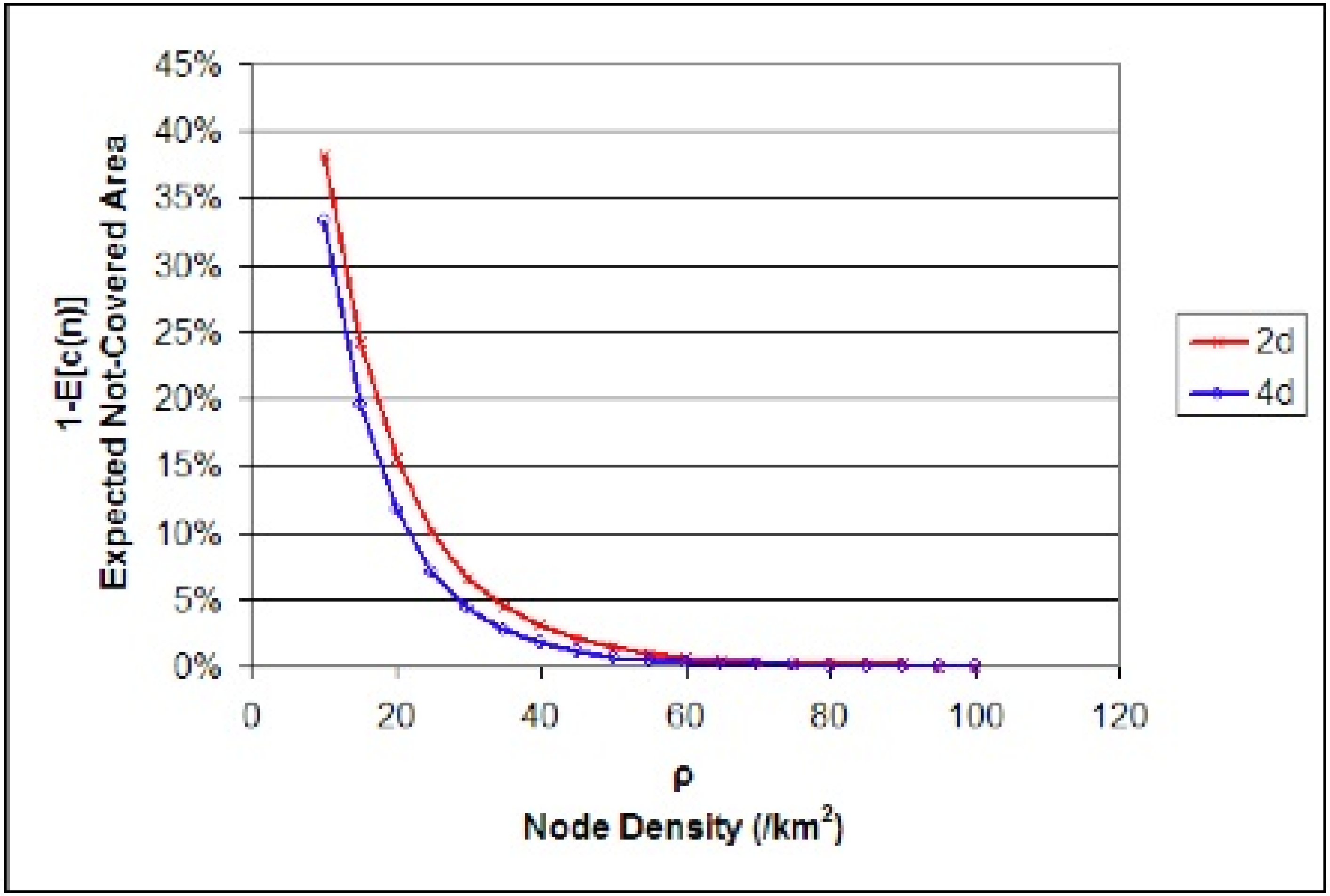

Figure 5. Expected area not covered by the proposed neighbor discovery algorithm against the node density.

Simmulation

- Randomly scattered n nodes
- 1500x1500 meters
- Uniform distribution
- Omnidirectional range 200m
- Directional range 400m

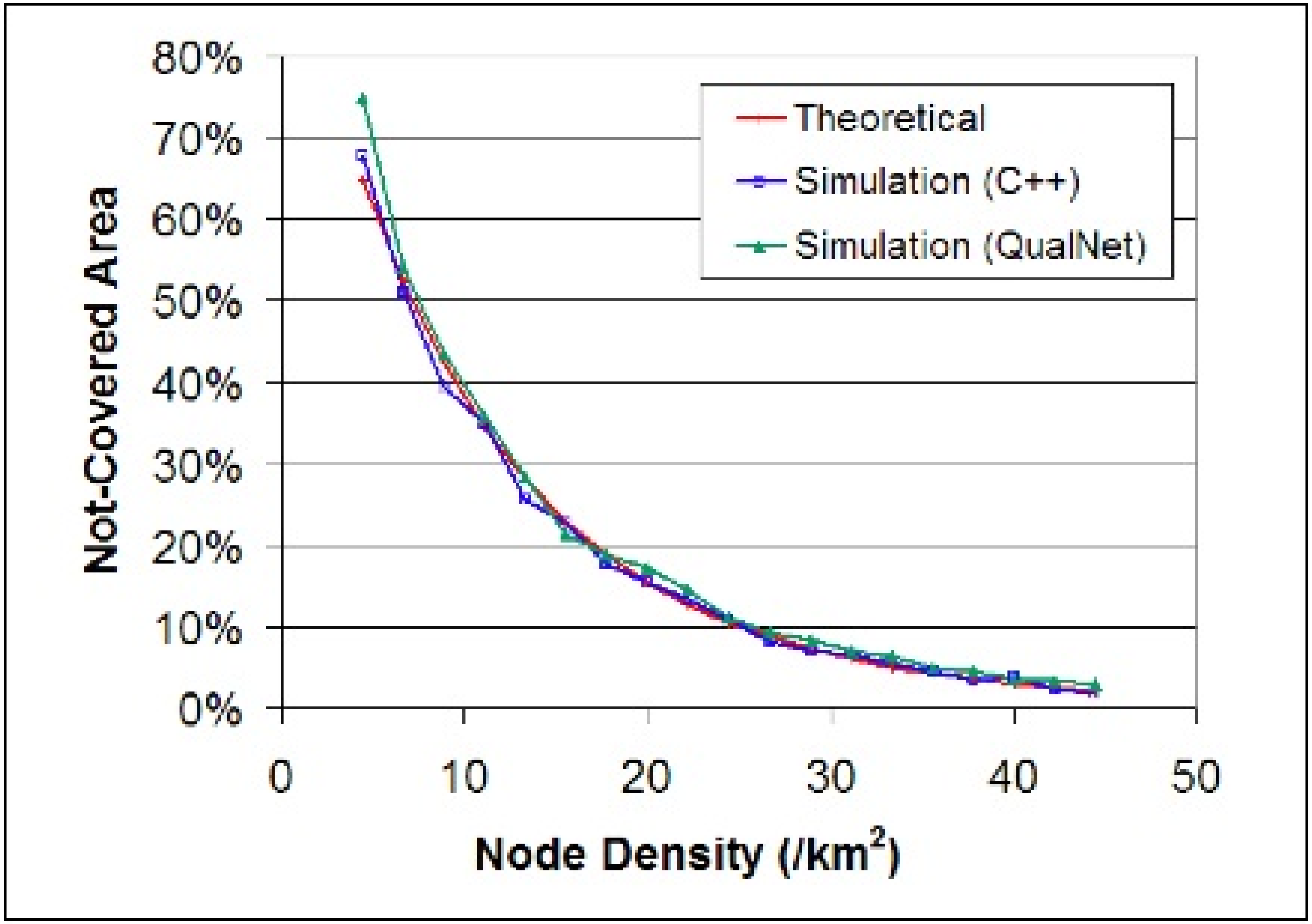

Figure 6. Actual not-covered area obtained from the simulation vs expected theoretical not-covered area.

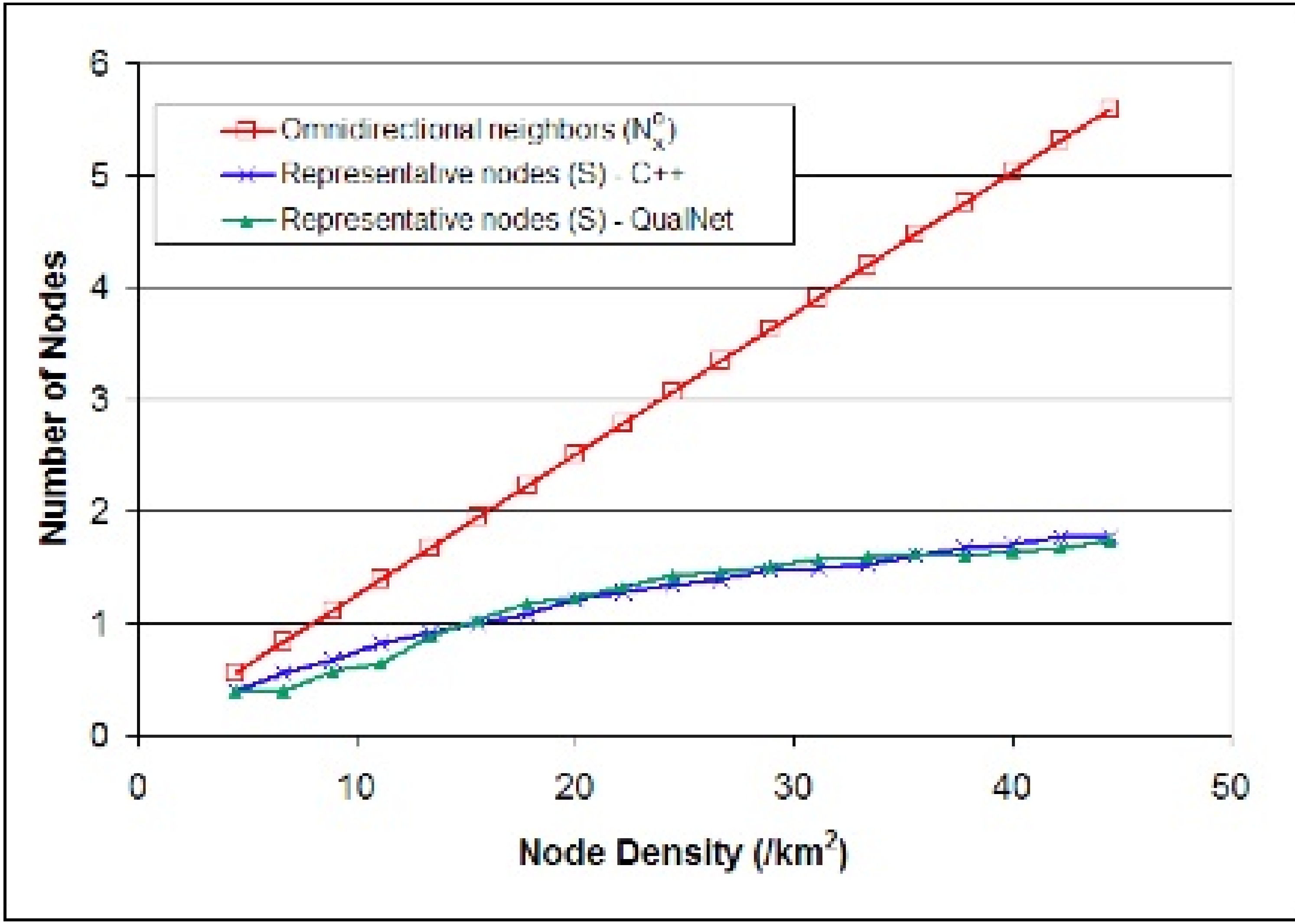

Figure 7. Average number of representative nodes against the node density.