CHAPTER 3

ARCHITECTURE: SINK PLACEMENT

This chapter discusses small world network concepts and the similarities between small world networks and WSNs that may result in a WSN being modelled as a small world network. In this chapter an algorithm to place multiple sinks at predefined points within the application area is discussed. It is shown that it is possible to model a WSN as a small world network by placing sink nodes at predetermined points within the application area.

3.1 INTRODUCTION

The final recipient node in a typical WSN application is usually a sink node which has specialised equipment that transmits the data to an end user. As shown in Figure 1.2 and Figure 1.3, the network architecture of a WSN can have one or more sinks. The benefit of having multiple sinks placed within a WSN application area is that the number of times that a message has to be re-transmitted to reach a sink is lower for multiple sinks placed across the application area than for a single sink. The reduction in message re-transmissions means fewer nodes receive and/or re-transmit a message, improving the sensor node lifetime and hence the WSN lifetime.

Since most nodes communicate primarily with a sink node, the placement of one or more sinks must be optimised to enable energy efficient communication within a WSN. An investigation is conducted on whether placing multiple sinks at specific points within a WSN application area will result in the development of a small world network. The advantage of small world networks is that the number of steps to route a message from a source node to a destination node, (where each node only has local information of their neighbours), increases logarithmically with the total number of nodes (Newman, 2003).

In a WSN modelled as a small world network, a message from any node within the application area will reach a sink node within a small, predetermined number of hops. The reason for modelling a WSN as a small world network is to reduce the number of messages sent and received by intermediate neighbouring nodes when an event has to be reported.

3.2 SMALL WORLD NETWORKS

In a small world network there are multiple long edges that connect local vertices (nodes) with distant nodes, thus enabling a faster spread of information or viruses etc. Small world networks share characteristics with both regular lattices and random graphs. The main characteristics of a small world network are a low diameter (like random graphs) and a high clustering coefficient (like regular graphs) (Watts & Strogatz, 1998).

In a small world network, the number of steps to route a message from a source node to a destination node, (where each node only has local information of its neighbours), increases logarithmically with the total number (N) of nodes (Newman, 2003). Two models of small world networks are discussed below (Radev, 2008).

3.2.1 Watts-Strogatz model

Watts and Strogatz showed that viable small world networks exist between the two extremes of completely regular or completely random networks. These networks have a high clustering coefficient like regular networks and small path lengths as in random networks. The small path lengths are due to "short cuts" that connect local vertices to long-range edges. Starting with a regular lattice structure, an edge in the graph is disconnected from its end point and rewired to a random node in the graph, until a random graph is obtained. The farther the node being reconnected to, the more the graph diameter is reduced. After only a few steps the diameter of the graph has been reduced dramatically while its clustering coefficient remains large. The Watts-Strogatz model uses a constant shortcuts probability, regardless of whether the node being rewired to is close to or remote from the source.

3.2.2 Kleinberg model

Kleinberg proposes a refinement where the geographical distance between two nodes affects the probability of an edge being rewired between them (e.g.$p \sim \frac{1}{d^2}$). Kleinberg proved a dependency between these small path lengths and the distance between them. A short path between two nodes (vertices) can only be found algorithmically if those nodes chosen to create a short-cut (i.e. those nodes with a long edge) are not chosen randomly, but are chosen related to the geometry of the application area (Kleinberg, 2000). Specifically, long range nodes are placed at a distance from a node that correlates to the actual distance between them in terms of an inverse power law relation, that is: d_{ij}^{-r}, where r = 2.

3.2.3 Similarities between small world networks and WSNs

The properties of WSNs that indicate similarities with small world networks are (Newman, 2003; Kleinberg, 2000):

- The overlap in wireless communication range means that most immediate neighbours of a sensor node are also neighbours of one another. A neighbour is any node that is in immediate radio range, i.e. able to receive and accurately decode data.
- Sink nodes in the network communicate with remotely located users (outside the WSN area). The remote station coordinates communication between sink nodes. (This long edge provided by the sink nodes reduces the diameter of WSNs).
- The average distance between two nodes is short (limited to the nodes' transmission and receiving range).
- There is no central authority to determine optimal routes. Routing is performed at each node with only information about the nodes nearest neighbours.

The questions required to be answered is firstly, how to determine the optimal number and placement of these sink nodes, in accordance with Kleinberg's theory, and secondly, can the number of messages required to route a message be reduced by placing sink nodes at specific points in the application area. The application area is assumed to approximate a two-dimensional grid, where starting from point (0, 0), each sink node is placed at the specified hop distance (i.e. number of hops multiplied by a nodes transmitting range).

3.3 ALGORITHM DESIGN

An algorithm to determine number of sinks required for a specific application area size and the placement of these sinks at specific points within the WSN application area is discussed in this section. Certain assumptions and definitions are provided to clarify the scope of the presented solution and equations.

3.3.1 Definitions

The following definitions are used:

- N = Total number of sensor nodes,
- R = Sensor node communication range,
- H = Number of hops
- S = Number of sink nodes
- X = Width of application area
- Y = Length of application area

3.3.2 Assumptions

- The application area is a two-dimensional rectangular or square grid, with the width and length specified.
- Starting from point $P(x_p, y_p)$, each sink node is placed at the specified calculated distance.
- The application area is always assumed to have at least one sink, irrespective of size and number of hops.

3.3.3 Calculation of number of sensor nodes

Full coverage of the application area by sensor nodes is not assumed and a generalised calculation to place sensor nodes in the application area is calculated as a function of the sensor range and the width and length of the area, i.e.

$$N = \left(\frac{X}{R} + 1\right) * \left(\frac{Y}{R} + 1\right) \qquad [3.1]$$

3.3.4 Calculation of number of sinks (long edges)

To calculate the number of long-range nodes (sinks) required within a WSN application area, the number of hops between the node farthest from a sink and the sink has to be specified. Small world networks are generally analysed to determine the maximum number of hops between two vertices. By specifying the maximum number of hops H to route a message between any two nodes in the network at the beginning, the researcher worked in the reverse direction of how small world networks are analysed.

The number of sink nodes required in the application area for the specified number of hops is calculated to conform to Kleinberg's thesis. Given the dimensions of the application area and the sensor nodes communication range, the number of long-range nodes (sinks) can be calculated as a function of the node range and the number of hops required within the network, as shown in Equation [3.2].

$$S = N * H^{-2} \qquad [3.2]$$

Given that N is dependent on X and Y, then from Equations [3.1] and [3.2]:

$$S = \left(\frac{X}{R} + 1\right) * \left(\frac{Y}{R} + 1\right) * H^{-2}$$

$$S = \left(\frac{X + R}{R}\right) * \left(\frac{Y + R}{R}\right) * H^{-2}$$

$$S = \frac{(X+R)*(Y+R)}{R*H^2} \qquad [3.3]$$

A sensor node is always able to reach a sink node within the specified number of hops. If the result from Equation [3.3] yields a value less than one, then the default value of the sink is set to one. That is, irrespective of size and number of hops, $S \geq 1$.

3.3.5 Placement of sink and sensor nodes

The sink nodes cannot be placed randomly if the topology is to conform to Kleinberg's small world algorithmic model. Each sink is placed the specified number of hops multiplied by the node range, from another sink. The application area is assumed to approximate a two-dimensional grid. If one sink is required, the sink is placed in the centre of the application area. For two sinks each sink is placed in the centre of half of the application area. For more than three sinks, the starting values from point $P(x_p, y_p)$ are calculated based on the simple Pythagorean Theorem in geometry. Figure 3.1 describes the algorithm to place sink nodes in the application area.

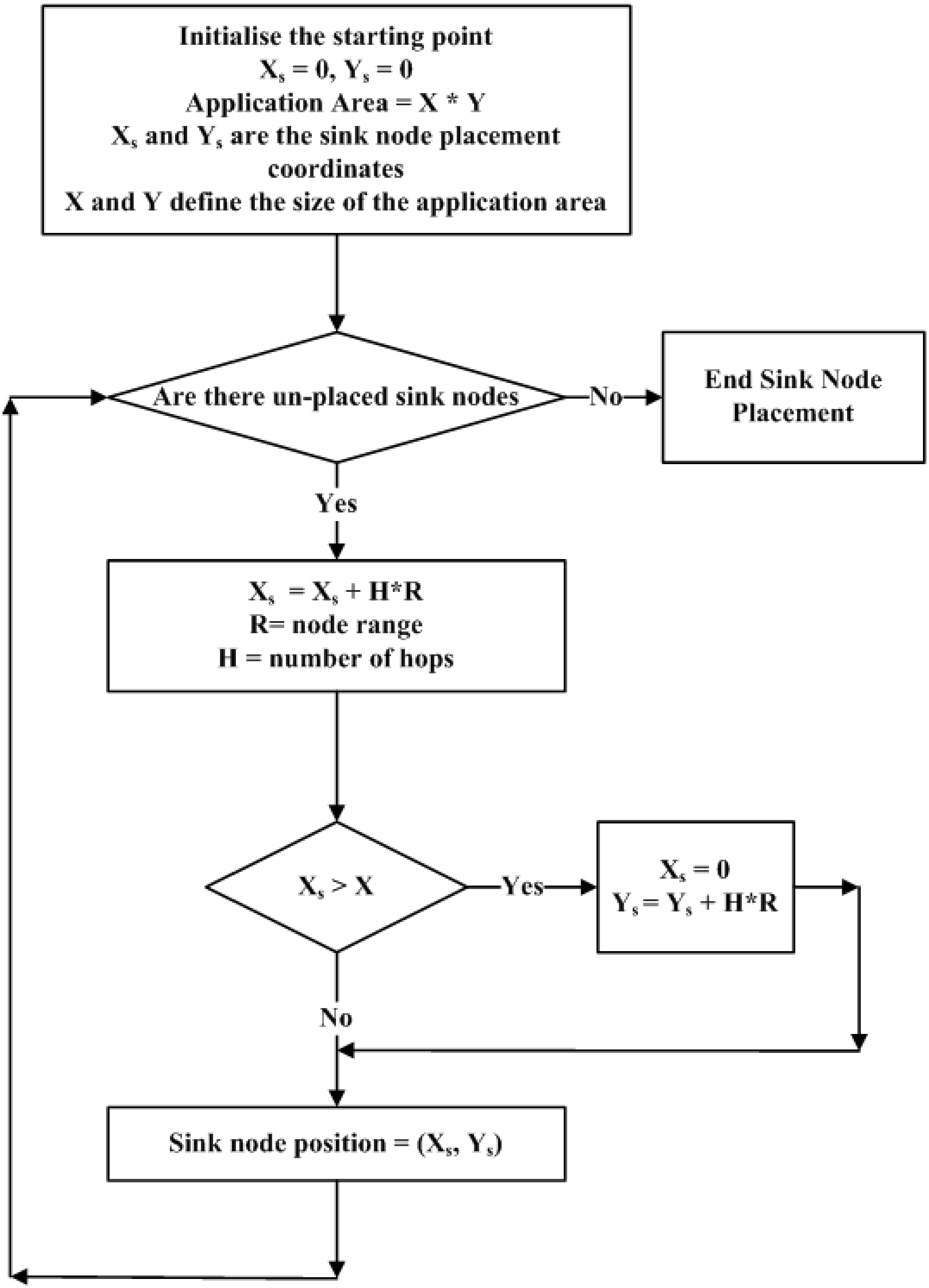

Figure 3.1: Sink node placement calculations

Two scenarios were evaluated for sensor node deployment. In the first scenario, the sensor nodes were placed the distance of the sensor range (R) from each other within the application area. In the second scenario, the sensor nodes were randomly deployed within the application area. The placement of the sink nodes is calculated as a function of the node range and the number of hops required within the network.

3.4 EXAMPLES OF THE USE OF SMALL WORLD NETWORKS IN WIRELESS SENSOR NETWORKS

Aldosari and Moura consider the optimisation of the network within a given class of random networks that exhibit small-world behaviour. Their results confirm that there is a specific range where the generated graphs exhibit a small-world phenomenon, i.e., high clustering coefficient and low path length, which strengthens Kleinberg's thesis that the long edge cannot be totally randomly allocated in a small world network (Aldosari & Moura, 2005).

Helmy showed that it is possible to model a WSN as a small world network by adding a small number of shortcuts. The author shows that the path length is reduced through the introduction of shortcuts without any significant impact on the structure of the network (Helmy, 2003). The key difference between Helmy's work and the proposed solution is that Helmy chooses a node at random to perform link re-wiring and link addition, which is similar to the Watts-Strogatz model. In the work discussed in this chapter the required number of sink nodes for the application area is calculated and the sink nodes are placed in specified locations from the sensor nodes according to Kleinberg's model.

Sharma and Mazumdar have suggested that by adding a few wires to a WSN, to simulate a long edge, the average energy expenditure per sensor node, as well as the non-uniformity in the energy expenditure across the sensor nodes, is reduced (Sharma & Mazumdar, 2005). The position of a single sink node is arbitrarily chosen.

Guidoni et. al discuss creating a heterogeneous sensor network based on small world concepts in order to optimise communication between sensors and the sink node (Guidoni et al., 2008). They consider two methods to model a small world network, namely directed angulation towards the sink (DAS) and sink node as source destination (SSD). In DAS, node location awareness is crucial to determine the routing path to the sink node. In the solution presented in this thesis, nodes do not need to be aware of the exact location of the sink; they use an available route path discovered during the initialisation phase. In SSD, short-cuts are added directly to the sink node, to create a small world network and reduce the number of hops. The added short-cuts are dependent on the range of the short-cut sensor and generally will be located close to a sink node. The SWR model uses multiple sinks so that each sensor is a maximum specified number of hops removed from a sink node.

3.5 RESULTS AND ANALYSIS

A program to simulate calculation of number and placement of the sinks was developed. The number of hops and sinks required for various application area sizes was calculated. The application area is assumed to be a two-dimensional square grid.

The results for the calculation of the number of sink nodes indicated that sensor node placement (predefined, i.e. scenario 1 or random, i.e. scenario 2) had no effect on the calculated number of sink nodes required for a given application area size. A sensor node is always able to reach a sink node within the specified number of hops in scenario 1. In random sensor node deployment, some sensor nodes may be placed outside the distance (hops times range) required to reach a sink node. Full coverage of the application area by sensor nodes is not assumed. The results in the following figures are for sensor nodes placed as for scenario 1.

Initially, the number of sinks was calculated using an adapted version of Equation [3.3], to determine if the node range had an effect on the model. Thus Equation [3.3] without considering node range in the application area width and length dimensions is:

$$S = \frac{X*Y}{R*H^2} \qquad [3.4]$$

The results for number of calculated sinks for a specified number of hops for various sizes of application areas ranging in size from 100x100 metres to 10000x10000 metres for a node range of 10m, 20m, 30m and 50 m is shown in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6 and Figure 3.7. These figures show that the number of sinks required in an increasing application area is dependent on the number of hops in an inverse power law of 2.

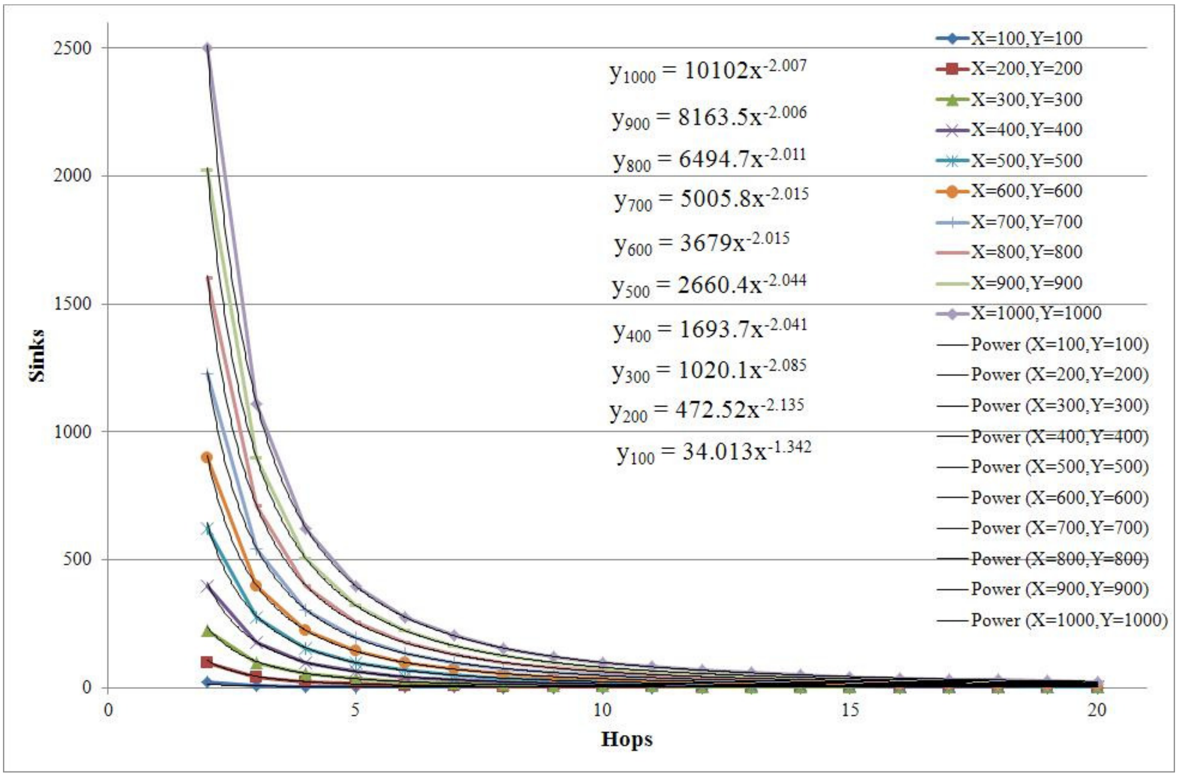

Figure 3.2: Node range is 10m

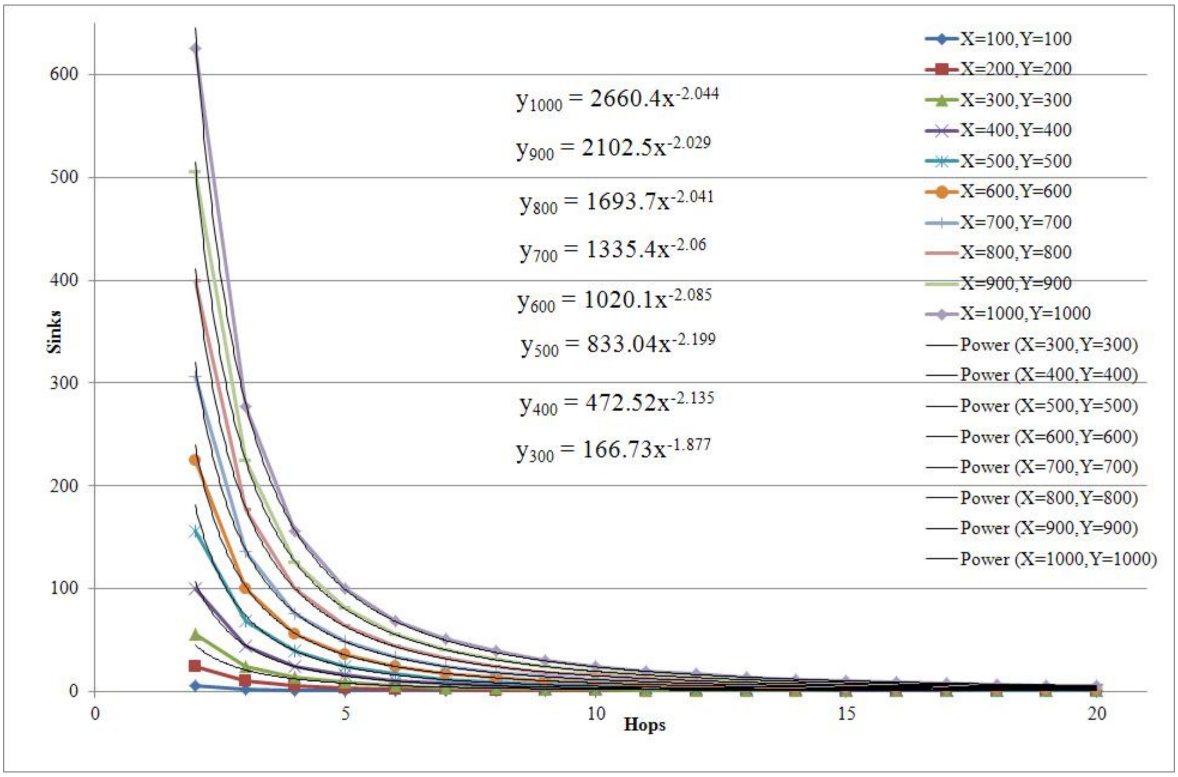

Figure 3.3: Node range is 20m

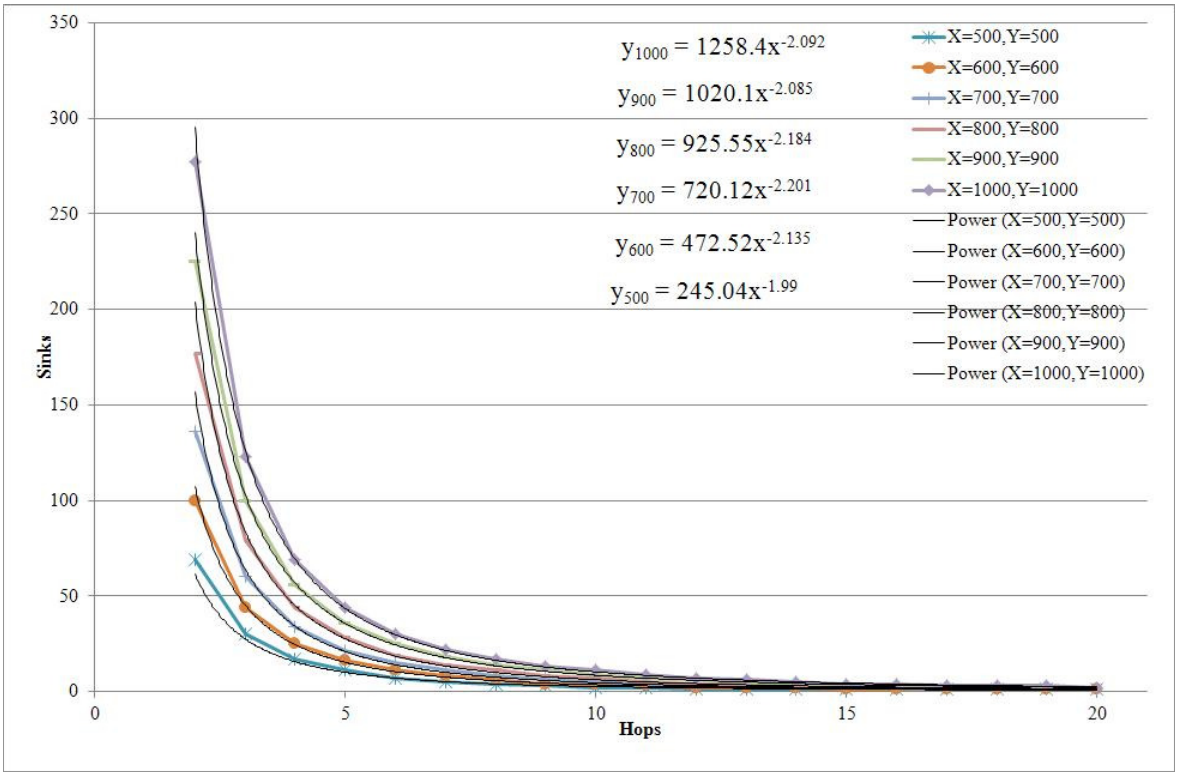

Figure 3.4: Node range is 30m for small application areas

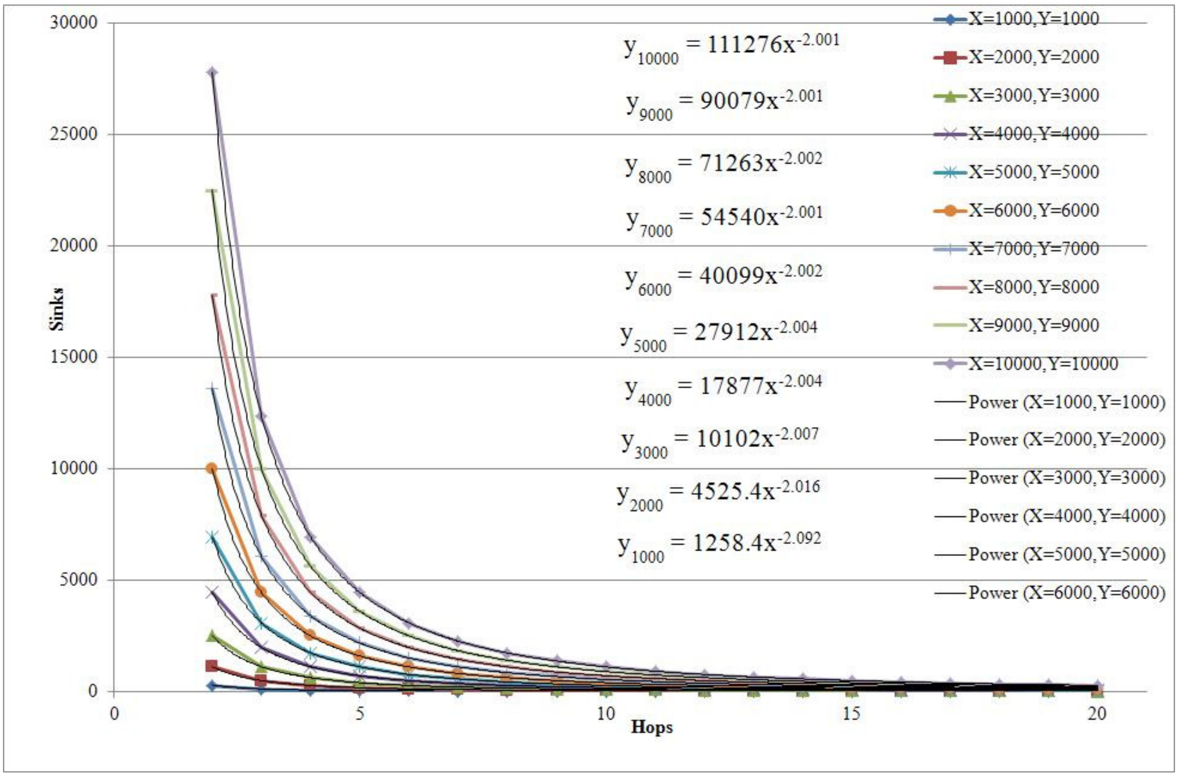

Figure 3.5: Node range is 30m for large application areas

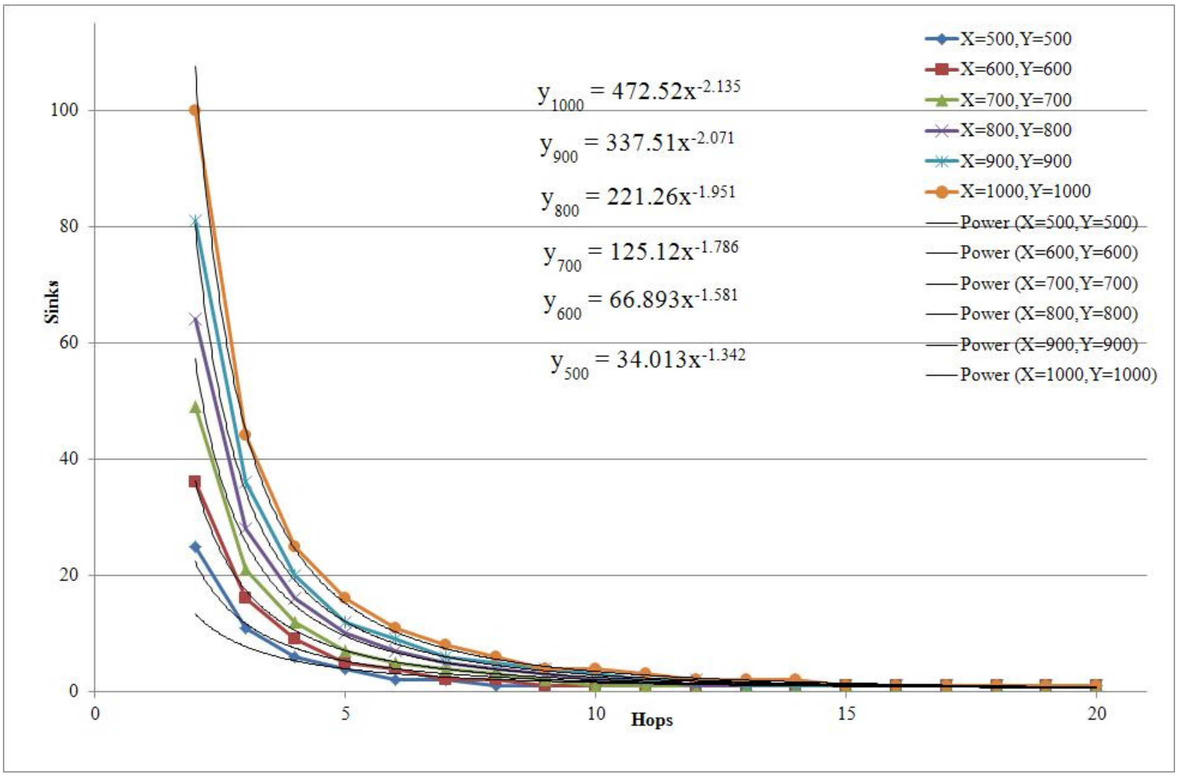

Figure 3.6: Node range is 50m for small application areas

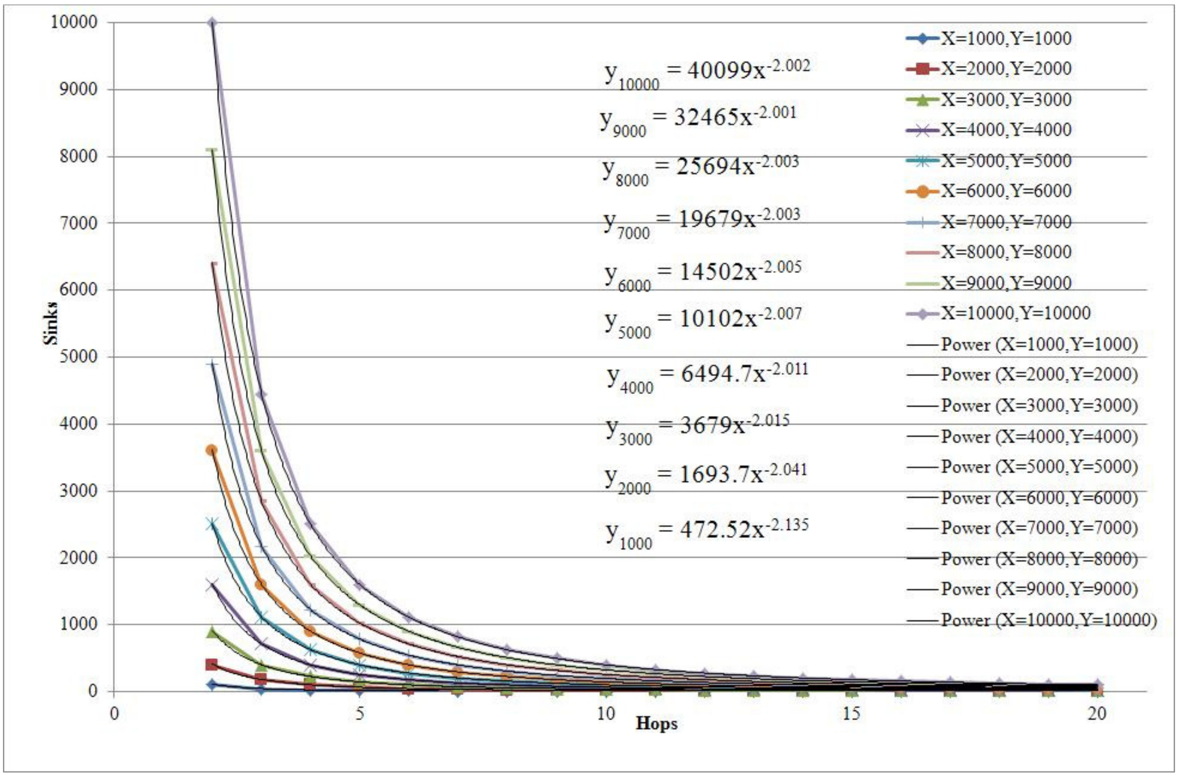

Figure 3.7: Node range is 50m for large application areas

The results from sink placement shown in the figures above confirm Kleinberg's thesis that optimum placement of the long edge (short cut) in a network is at d_{ij}^{-r}, where $r = 2$. Note that the results for small application areas are not always dependent on the number of hops in an inverse power law of approximately 2.

It is possible to model a WSN as a small world network, by using sink nodes to create the long edges. The sink nodes are placed at a distance from a sensor node that correlates to the actual distance between them in terms of an inverse power law relationship between number of hops and number of required sinks. Note that as the range increases, the relationship no longer holds for small application areas, implying a correlation between range and number of hops. To test this theory, the range factor is included as shown in Equation [3.3].

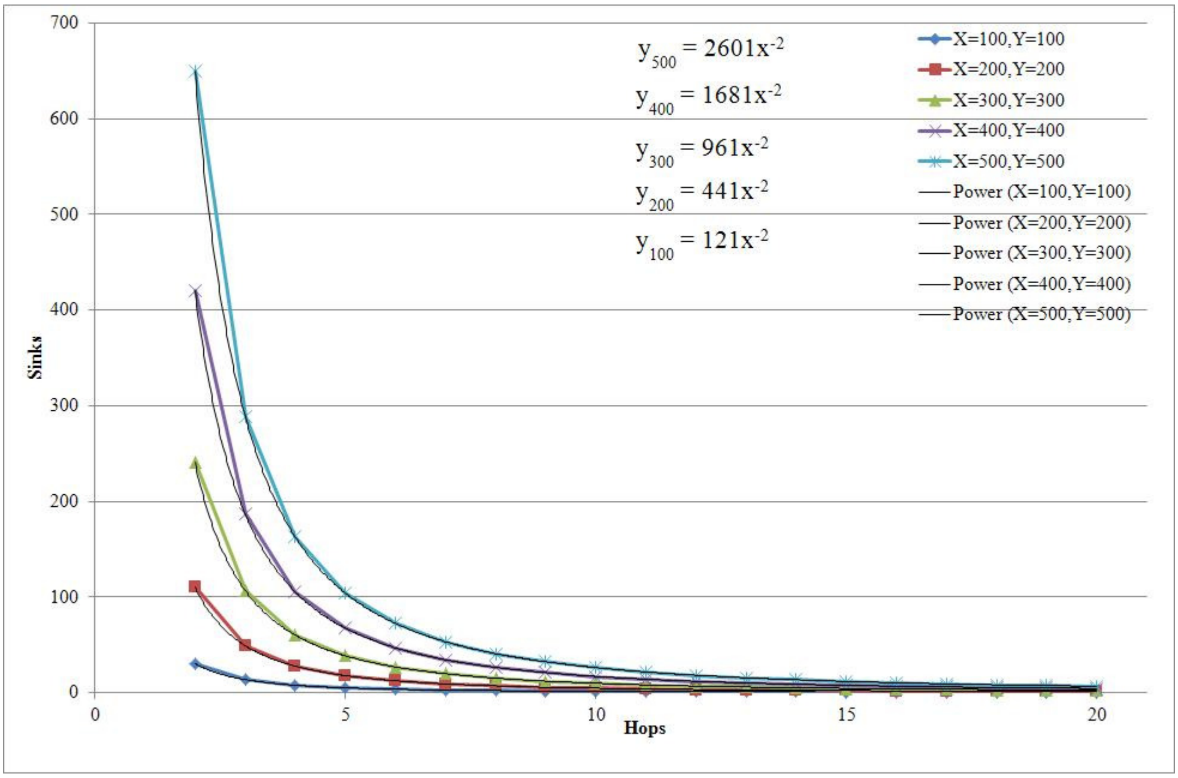

Figure 3.8: Sinks vs. hops (range=10m)

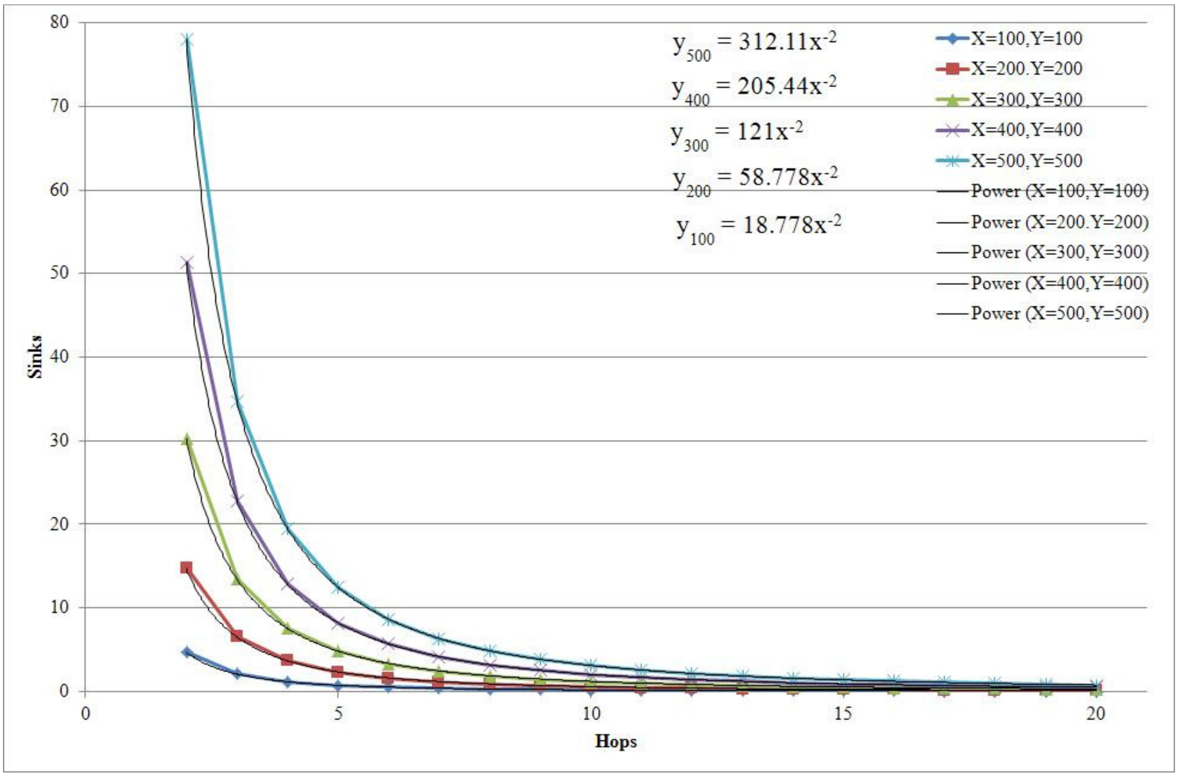

Figure 3.9: Sinks vs. hops (range=30m)

From Figure 3.8 and Figure 3.9 one can see that the hypothesis of simulating a small world in smaller application areas is valid if the node range is taken into consideration. The node range has an impact in smaller application areas because the range is 25% to 30% of the application area's length. For larger application areas (i.e. greater than 1000mx1000m), the node range has a negligible effect on the calculation of number of sinks and placement of sinks.

3.6 CONCLUSION

In this chapter Kleinberg's thesis that the long edges cannot be chosen randomly has been used to model a WSN as a small world network. This differs from previous research that has tried to model a WSN as a small world network by randomly rewiring links. The algorithm described in this chapter shows that it is possible to model a WSN as a small world network by placing sink nodes at specific pre-calculated points within the application. The result is that a message from any node within the application area will reach a sink node within a small predetermined number of hops. This will reduce the number of messages sent and received to all nodes.

In the next chapter an algorithm that creates one or more routes for each sensor node to one or more sinks within the wireless application area is discussed. It will be shown that there is a reduction in the number of messages transmitted within the network when the WSN is modelled as a small world network. The routing algorithm creates one or more route paths for the specified number of hops.

3.7 DECLARATION

The work in this chapter has been published in the following Conference:
2009 International Conference on Wireless Networks and Information Systems (WNIS 2009), 28-29 December 2009 in Shanghai, China