Reachability Analysis for spatial Deployment of Heterogeneous Nodes in a WSN

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ABSTRACT
Wireless Sensor Networks are taking a big step forward to productive deployments. Initially the Wireless Sensor Networks consisted of homogeneous deployment of identical nodes.. With the passage of time the heterogeneous networks have also come into existence. Less attention has been paid to the heterogeneous deployment of sensors and the amount of research work done with heterogeneous networks is still very less as compared to homogeneous networks. For ensuring reliable data communication among nodes of different capabilities in a heterogeneous network we have focused on the broadcast reachability of the sensor nodes to assure that any type of node (weaker/stronger) is within the transmission range of any other type of node keeping in mind, the asymmetric links among nodes in a heterogeneous network. Broadcasting is one of the fundamental data dissemination mechanisms in mobile ad hoc networks. In this paper, we have considered deployment of sensing nodes of heterogeneous capabilities in a three-dimensional region and it is observed that a few strong sensor nodes can reduce the total requirement of sensor nodes in a Wireless Sensor Network. This observation is supported by mathematical analysis.

General Terms
Broadcast, Connectivity, Spatial et. al

Keywords
Poisson, Heterogeneous, Broadcast Reachability, Communication.

1. INTRODUCTION
Wireless Sensor Networks (WSNs) is a fast growing and exciting research area that has attracted considerable research attention in the recent past. This has been fueled by the recent tremendous technological advances in the development of low-cost sensor devices equipped with wireless network interfaces [5]. Recently, the research on wireless sensor networks has been very intense under all aspects ranging from routing to MAC (Medium Access Control) [8] [6] and power off mechanisms [8, 7, 4]. WSNs promise to advance biological and physical sciences by enabling measurements in environments where traditional centrally wired sensors are impractical or impossible because of physical constraints. Once a WSN has been deployed, it is expected to operate for extended periods of time and without human intervention. The original version of WSN called for a large number of homogeneous nodes that would monitor the environment and perform collaborative in-network data processing. However, the limitation of the nodes with same capabilities (homogeneous nodes) led to the deployment of a WSN consisting of nodes with different capabilities (heterogeneous nodes).To address the fundamental problem of the ample number of nodes, and ample resources per node , the sensor network research community has been increasingly exploring WSNs with heterogeneous sensor nodes. Heterogeneous wireless sensor networks provide endless opportunities due to their extendable capabilities such as different computing power, sensing range, and communication range.

Apart from optimal coverage, for efficient working of a WSN, connectivity is of equal importance for reliable communication of data among sensor nodes. Connectivity is a key issue for WSNs regarding its tight relation to performances such as reliability and life-time [1], [3]. To improve the detection performance, it is often quite useful to fuse data from multiple sensors. Data fusion is considered in [2], where a cluster head fuses the data from sensor nodes and transmits the result to sink. But this approach requires more data and control messages, which is possible by communication among sensors. In WSN with heterogeneous nodes, connectivity (which is required for data communication) can become quite complicated due to nodes of different capabilities, which creates asymmetric links among nodes and may not guarantee that a packet sent by a low power sensor node can reach to the high power sensor nodes. In [9] a topology control mechanism is considered for ensuring symmetric connectivity by making sure that the distance between nodes of higher strength and nodes of lower strength is not larger than the maximum communication range of nodes of lower strength which includes an overhead of generating candidate positions for each type of sensor node.

In this paper, to overcome the above mentioned problems in an efficient manner, we make use of broadcast reachability to provide data transmission. Broadcast reachability "*which is the probability that a data packet transmitted by a high power sensor node can reach all other sensor nodes in a network.*" is one of the important Quality of Service parameters of WSN. Here, we consider two types of nodes. (i) type I nodes and (i) type II nodes. The type I nodes are the higher power nodes with stronger transmission range and more resources, having transmission radius as r_{T1} , while the type II nodes include tiny, low power and resource constrained devices, having weaker transmission range, having transmission radius as r_{T2} .

The remainder of the paper is organized as follows. Section II spells out the deployment of heterogeneous/homogeneous nodes. In section III we study and analyze the broadcast reachability of homogeneous sensors. In section IV we study and analyze the broadcast reachability of heterogeneous sensors. Section V provides the analysis results of both the homogeneous and heterogeneous networks, and section VI includes concluding remarks.

2. DEPLOYMENT OF SENSORS

A **sensor node**, also known as a 'mote', is a node in a WSN that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. A sensor network is applied to various fields from the special application fields such as wild environment monitoring, industrial machine measurement, and military-purpose measurement to the daily application fields such as fire monitoring and pollution monitoring. In this paper, we consider a space of volume V, which is a sub region in Ω. In space V, N heterogeneous sensor nodes are deployed uniformly and hence density of nodes is $\lambda = N/V$ per unit volume. We consider the deployment of nodes in three ways. (i) All the N sensors are of higher sensing capabilities, in this case we write n_1 for N (ii) All the N sensor nodes are of usual or comparatively lower sensing capabilities, in this case we write n_2 for N (iii) A mixture of both type of nodes, i.e., n_1 sensors of higher sensing capabilities and n_2 sensor nodes of usual/comparatively lower sensing capabilities where N= n_{1+} n_2.The first two deployments are those of homogeneous sensor nodes, and the third deployment is of heterogeneous sensor nodes. The transmission range of type I and type II Sensor nodes are denoted as r_{T1} and r_{T2} respectively.

($r_{T1} >> r_{T2}$).

3. HOMOGENEOUS NETWORK

A homogeneous sensor network consists of sensors nodes with same capabilities in terms of sensing range, communication range and resources. We consider the broadcast recahability of homogeneous nodes, in a three dimensional network according to Poisson distribution. Assuming that the sensors are deployed in a space of volume V, the density of nodes is $\lambda = N/V$, where N is the total number of nodes and the volume of the sub region in Ω is V. For a sensor network with density λ, obeying Poissionian distribution, the probability that a node I is within the reachability of broadcast from any other nodes in the network is defined as:

$$P_{r\,\text{hom}} = 1 - P_r(0) \quad (1)$$

$$= 1 - e^{-m},$$

where $m = \overline{V}\lambda$ and $\overline{V} = \frac{4}{3}\pi\, r^3$

If we assume statistical independence for all the nodes, the probability that other N-1 nodes are reachable, then the broadcast can be calculated as

$$P^{N-1}{}_{r\,\text{hom}} = \left[1 - P_r(0)\right]^{(N-1)} \quad (2)$$

Thus, the threshold broadcast reachability is

$$P^{N}{}_{r\,\text{hom}} = \left[1 - P_r(0)\right]^{(N)}, \quad (3)$$

Where N=n_1 for type I nodes and N=n_2 for type II nodes.

4. HETEROGENEOUS NETWORK

A heterogeneous sensor network consists of sensors nodes with different capabilities in terms of sensing range, communication range and resources. We consider the broadcast recahability of heterogeneous nodes, in a three dimensional network according to Poisson distribution. Assuming that the sensors are deployed in a space of volume V, the density of nodes is $\lambda = N/V$, where N is the total number of nodes and V the volume of the sub region in Ω. For a sensor network with density λ, obeying Poissionian distribution, the probability that a node I is within the reachability of broadcast from any other nodes in the network is defined as :

$$P_{rhet} = 1 - P_{r1}(0)P_{r2}(0) \quad (4)$$

$$= (1 - e^{-m1}e^{-m2}),$$

where $m = \overline{V}\lambda$ and $\overline{V} = \frac{4}{3}\pi\, r_T^3$

If we assume statistical independence for all the nodes, the probability that other N-1 nodes are reachable, then the broadcast can be calculated as

$$P^{N-1}{}_{rhet} = \left[1 - P_{r1}(0)P_{r2}(0)\right]^{(N-1)} \quad (5)$$

Thus, the threshold broadcast reachability is

$$P^{N}{}_{rhet} = \left[1 - P_{r1}(0)P_{r2}(0)\right]^{(N)} \quad (6)$$

$$= \left[1 - P_{r1}(0)P_{r2}(0)\right]^{(n_1+n_2)}$$

5. COMPARATIVE STUDY OF HOMOGENEOUS AND HETEROGENEOUS NETWORK

The sensor nodes (type I and/or type II) are deployed in 450*40*90 cubic unit volume. A comparison of the broadcast reachability due to homogeneous deployment of type I/type II nodes is shown in Fig. 1. Correspondingly Fig. 2 gives the broadcast reachability probability when a heterogeneous mixture of type I and type II nodes is deployed to form the network. While making a heterogeneous network of nodes we consider three types of cases. (i) when the ratio of the stronger to weaker nodes i.e., type I node: type II node is kept as 1:2. (ii) when the ratio of the stronger to weaker nodes i.e., type I node: type II node is kept as 1:3, and (iii) when the ratio of the stronger to weaker nodes i.e. type I node: type II node is kept as 1:4.

Figure 3 provides a comparison of the affect of homogeneous and heterogeneous nodes on the broadcast reachability. For numerical evaluation we are assuming $r_{T1} = 2r_{T2}$ (for heterogeneous deployment).

From Figure 1 we infer that in case of homogeneous sensor nodes the probability of reachability of type I nodes is greater than the probability of reachability of type II nodes, when same number of nodes is deployed. We can clearly see from the figure that for 160 type I nodes the probability of reachability is 1, whereas for the same number of type II nodes the probability of reachability is approximately 0.77. Further, the complete reachability (probability 1) is attained by deploying 160 type I nodes, while the same probability is attained by deploying 290 type II nodes.

From Figure 2 we can see that as the ratio of type I and type II nodes increases the probability of reachability also increases. We observe that when the ratio of type I and type II nodes is 1:2 then the probability of reachabilty for 60 nodes is 0.98. As the ratio decreases to 1: 3 the probability of reachability decreases to 0.92, and with a further decrease in the ratio i.e., 1:4, the probability further decreases to 0.84. Therefore, we can clearly see that a type I nodes greatly contributes to the higher probability of reachability in the network.

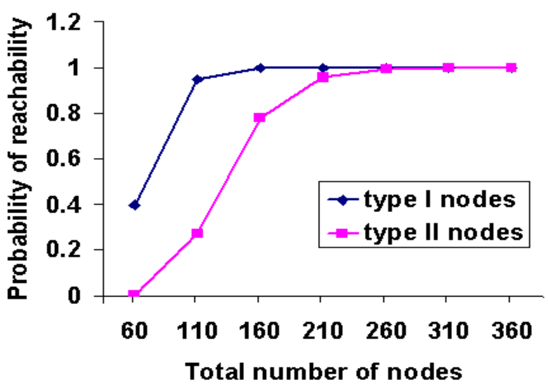

Fig. 1 Effect of type I and type II nodes on broadcast reachablity in homogeneus network

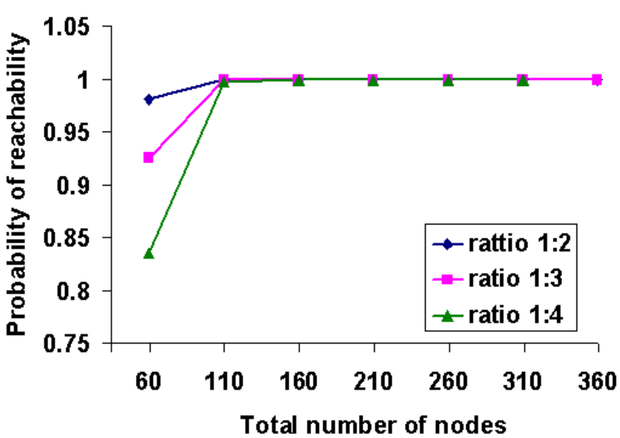

Fig. 2 Effect of ratio of type I and type II nodes in heterogeneous network

Figure 3 provides a comparison among the Heterogeneous and Homogeneous deployment of sensor nodes, which shows that a small addition of type I nodes in type II nodes considerably improves performance of the network. As the concentration of type I nodes increases the broadcast reachability probability increases in a significant manner. For example complete reachability is attained by 290 number of type II nodes. The same is attained by 160 nodes (32 nodes of type I and 128 nodes of type II) in the ratio 1:4; it is attained by 110 nodes in the ratio 1:3 and 90 nodes in the ratio 1:2.Morever complete reachability, by exclusive deployment of type I nodes, is achieved by 150 nodes. The same is achieved by 160 nodes of heterogeneous combination o type I and type II nodes in the ratio 1:4

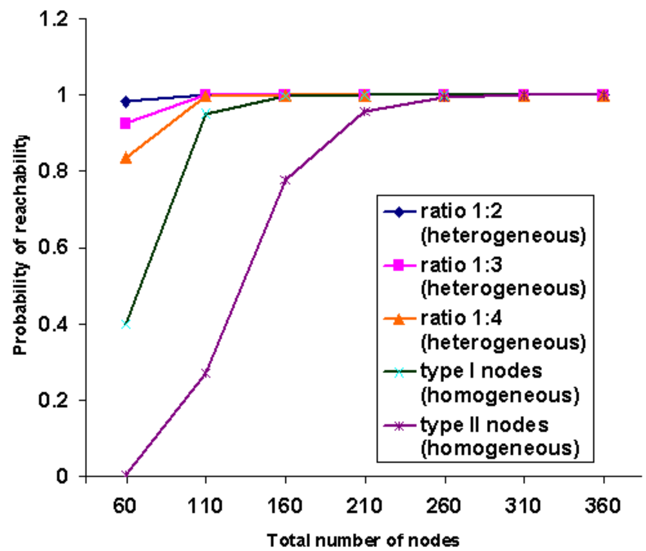

Fig. 3 comparison of the heterogeneous and homogeneous network

6. CONCLUSION

We considered deployment of homogeneous nodes distributed randomly in region of volume V with Piossonian distribution and calculated the reachability probability for the increasing number of nodes. It is observed that maximum reachability probability is achieved by lesser number of high capability nodes compared to low capability nodes. Next we consider heterogeneous deployment of two types of nodes in varying ratio. It is observed that an addition of small number of higher capability nodes increases the performance significantly.

7. REFERENCES

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