EFFICIENT NETWORK DESIGN FOR ENVIRONMENTAL MONITORING APPLICATIONS
A Practical Approach

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Abstract: The deployment of a wireless sensor network is highly dependent on the target environment. Once the characteristics of the desired area are know, the question of network size arises. Factors like transmission power level, cost of network deployment and the coverage area directly affect the size of the network. This paper analyzes the behaviour of a typical multi-hop wireless sensor network operating in an outdoor environment. By considering two separate cases; fixed cost and fixed deployment area, we present best network set-up statistics based on actual received power measurements.

1 INTRODUCTION

The concept of a wireless sensor network (WSN) involves the integration of sensing, processing and communication abilities to create highly autonomous networks. In order to combine sensors, processors and radio devices, a detailed study of the desired application as well as the capabilities of the available hardware has to be done. Wireless nodes are the building blocks of WSNs; sensing, processing and communicating abilities are integrated to produce miniature devices that can form and maintain a network. The origins of WSN trace back to the distributed networks program (Lacoss, 1986) launched by DARPA in the late 80s using bulky wireless devices to convey information to the end-user. The advancement in the CMOS technology has led to extremely small devices with exceptionally high processing abilities giving rise to tiny wireless nodes (MicaZ, Telos etc. by Crossbow Technologies).

The set-up and operation of a WSN is highly dependent on the application. The main emphasis of the work presented in this paper is towards environmental monitoring scenarios. Environmental data collection requires the collection of multiple sensor readings from geographically different locations over time. These readings need to be transmitted to a base station, where analysis can be done to deduce results (Sun, 2010). From the network deployment perspective, a large number of nodes need to be placed (randomly or deterministically) having the ability to relay/forward information to the sink node.

This paper presents a model for the efficient deployment of a WSN in an outdoor environment. By carrying out received power measurement analysis for a specially designed general purpose wireless sensor node in an outdoor environment, simulations have been done for the cases of fixed cost and fixed coverage area. The designed application provides the required network size, the transmission power requirement and the coverage area statistics for different combinations of the input parameters.

This paper is organized as follows; Section 2 presents an overview of the WSN architecture, Section 3 has the procedure for received signal strength measurements, Results and analysis is presented in Section 4 and the paper concludes with a summary in Section 5.

2 WSN ARCHITECTURE

2.1 Setup Requirements

Environmental monitoring usually requires periodic data logging, giving rise to extremely low data rates.

Compared to traditional single hop networks, the WSN has some unique features (Ye, 2009);

1) All nodes can form a network based on some protocol.
2) All nodes can sense and route the information to nearby nodes.
3) Nodes can join or leave the network without any management issues.

The above mentioned requirements enable the nodes to operate in a highly collaborative manner thereby preserving the energy supplies for the longer operation.

2.2 Network Structure

As mentioned in Section 2.1, the network topology of the WSN is governed by the protocols adopted by the nodes. For the results presented in this paper, a hierarchical network topology is assumed based on the low energy adaptive clustering hierarchy (LEACH) (Baghyalakshmi, 2009). According to this approach, all the nodes in the network consider themselves as either cluster heads (CH) or member nodes (MN). Figure 1 shows a graphical representation of such a network.
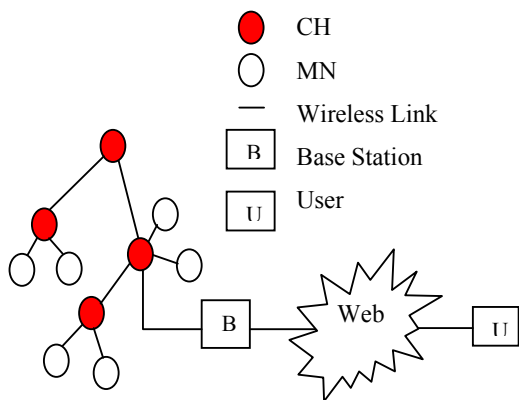

Figure 1: Network layout of a typical WSN for environmental monitoring.

The CH has the responsibility of collecting the data from its MNs and relaying it to the next-hop CH until it reaches the base station. MNs only communicate with their respective CH using the least possible transmit power (P_t), whereas CH can adjust their transmit power levels based on the requirement of the network topology.

3 RECEIVED SIGNAL STRENGTH (RSS) MEASUREMENTS

RSS measurements were carried out using the custom designed wireless sensor node in an open outdoor environment (University stadium). The transceiver unit, CC2420 (Chipcon, 2005), used on the used wireless sensor node, offers five different P_t settings including 0dBm. Moreover, the CC2420 has the ability to calculate the RSS of the received packet fairly accurately.

The actual RSS of a packet is not considered to be an accurate representation of the environmental conditions for large WSNs deployments as packets can be received with extremely low RSS (<90 dBm). Instead a different metric, packet receive rate (PRR), is taken into account to represent the fraction of packets received. PRR enables a much closer understanding of the channel conditions by considering packet loss; which is vital in environmental monitoring applications.
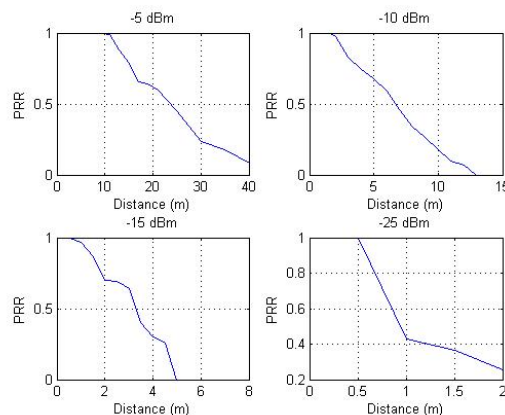

Figure 2: PRR with varying transmitter-receiver separation for four different P_t in an outdoor environment.

Measurements for PRR relative to the transmitter-receiver separation were done for four P_t levels as shown in Figure 2. For 0 dBm, the measurements were inconclusive as a perfect reception was achieved even up to a separation of 70 m. The data presented in Figure 2 was used as a base for determining the signal quality at a given P_t. All the statistics presented in the following sections of the paper are based on these measurements.

4   RESULTS AND ANALYSIS

4.1   Fixed Cost and PRR

For this case, the cost of the network, in the number of nodes available, and the PRR are provided as the input to the model. This case presents the situation in which, the user has a fixed number of nodes and he requires a certain PRR as a measure of the QoS. Figure 3 shows the results of a network comprising of 50 nodes operating at a PRR of 0.9.
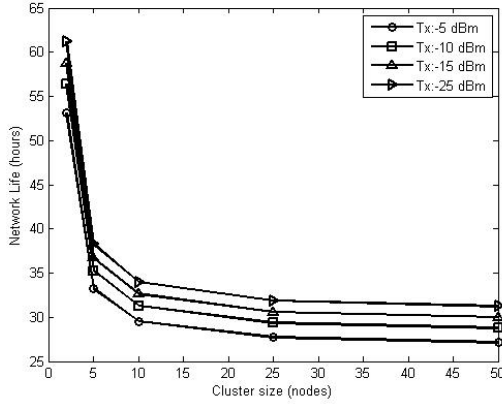

Figure 3: Network life (in hours) for different cluster sizes for a network comprising of 50 nodes operating at a PRR of 0.9 for an outdoor vicinity of 50 m^2.

From Figure 3, it can be observed that, for a fixed number of nodes, regardless of the transmit power level used; a lightly packed cluster topology results in the maximum possible life of the network. When the deployment area is also fixed, this condition implies a larger number of lightly packed clusters operating fairly close to each other. Due to less inter-cluster distance, low P_t is required to fulfil the communication requirements between adjacent clusters, hence increasing the overall operating life of the WSN. As the individual clusters become populated, the separation between them must be increased to ensure maximum coverage of the given area, thereby increasing the requirement of P_t, which results in lowering the network operating time.

Tables 1 and 2 present the network lifetime statistics for the case presented in Figure 3 for two different PRR requirements. The PRR is a measure of the link quality and is not dependent on the network life time as observed from the figures in Table 1 and Table 2. The maximum inter-cluster spacing is inversely proportional to the PRR and is extracted from the measurement data presented in

Figure 2. As the desired PRR is decreased (0.5 for worst case), the inter cluster spacing increases enabling the network to span a much larger area as compared to a PRR of 0.9.

Table 1: Network life (hours) and corresponding maximum inter-cluster separation for PRR=0.9.

Cluster Size (nodes)	P_t (dBm)			
	-5	-10	-15	-25
2	53	56	59	61
5	32	35.13	37	38.3
10	30	31	33	34
25	28	29	31	32
50	27	29	30	31
Inter-cluster Spacing (m)	12.6	2.5	1.3	0.6

Table 2: Network life (hours) and corresponding maximum inter-cluster separation for PRR=0.5.

Cluster Size (nodes)	P_t (dBm)			
	-5	-10	-15	-25
2	53	56	59	61
5	32	35.13	37	38.3
10	30	31	33	34
25	28	29	31	32
50	27	29	30	31
Inter-cluster Spacing (m)	23.7	6.7	3.3	0.9

4.1.1   End-to-End Latency Analysis

The total time required for a packet from its generation to the delivery at the base station is referred to as the end-to-end latency. For environmental monitoring applications in critical situations (hospitals etc.), the latency plays an important role and must be minimized for the data to be of any meaningful value. NS-2 simulations of the network mentioned in Figure 3, give the stats provided in Figure 4.

When small cluster sizes are adopted, a large number of clusters are required to cover a given region. Although this increases the network operation life, but makes the packet reach the base-station over multiple hops. Delay at individual hops adds up and becomes significant due to the sleep cycles and congestion conditions.
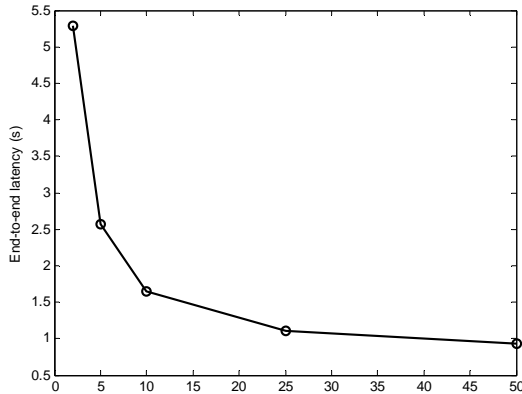
Figure 4: End-to-end latency for a 50 node network operating at varying cluster sizes at a PRR of 0.9 for an outdoor vicinity of 50 m^2.

As it can be observed from Figure 4, the latency could be as high as 5.2 seconds.

4.2 Fixed Area and PRR

Practical situations might require the user to specify the coverage area instead of the cost (as in Section 4.1). For a PRR of 0.9 and an area of 50 m^2 the network size (in clusters) is presented in Figure 5.
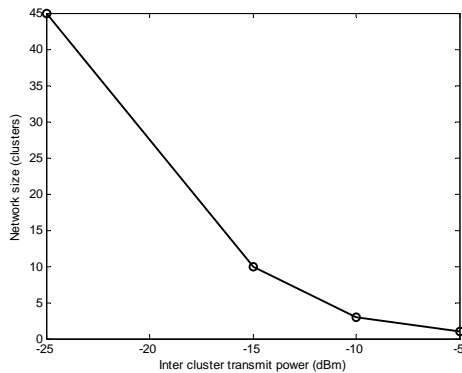

Figure 5: Network size (clusters) at different inter-cluster transmission powers with a PRR of 0.9 for an outdoor vicinity of 50 m^2.

As expected, for a low P_t a larger number of clusters are required. The number of nodes within a cluster is dependent on the actual intra-cluster transmission power levels selected which depends on the implementation scenario.

5 CONCLUSIONS

WSN deployment is a tricky job unless handled wisely. This paper presented a model based on actual PRR measurements to study the relationship between critical factors like network lifetime, end-to-end latency and the coverage plan for a given area. By analyzing the simulation results, a trade-off between network life and the end-to-end delay was observed. Based on the target environment and the required parameters, this model tends to provide the best deployment plan according to the desired PRR.

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