Data Gathering System for Watering and Gas Pipelines Using Wireless Sensor Networks

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***Abstract*—In this paper we discuss a small size experimentally implemented pipeline watering system, in which the pressure sensors are placed at carefully selected points. In our prototype, the TelosB motes, integrated with the pressure sensors, communicate in real time with each other and also with the base station according to the specifically designed wireless network protocol. The reason to choose a WSN as an infrastructure in our study is to let the system work without the need of extra cabling. Such a system incorporates both efficiency and flexibility, and provides the users with an automatic controlled water/gas system based on the sensor data. In our work, data was continuously measured using a pressure sensor and transferred to a central monitoring station via IEEE 802.15.4 wireless sensor network for storage and display. TelosB wireless motes were programmed with nesC and a graphical user interface was used to capture and display incoming measurements for all selected points being monitored. Evaluation of the system was done based on the WSN performance criteria (packet loss and network lifetime) and also based on the accuracy of the collected pressure data. In both respects the system performed very satisfactory and has been successfully implemented.**

Keywords: - wireless sensor networks; remote monitoring;nesC; TinyOS; water pipeline; TelosB; pressure sensor.

I. INTRODUCTION

The increase in the processing and integration capacity of electronic devices, as well as the advances of low power wireless communications have enabled the development of unwired intelligent sensors for a wide set of applications. The advent of small, low-cost and power efficient wireless sensor hardware is driving the development of applications in different industrial sectors, remote process control and also agriculture. Of particular interest here is the ability to remotely monitor water and gas pipeline pressure data. Efficient and accurate use of water resources has become very significant especially in recent time due to the global warming issues. Least but not last, the watering pipelines used in agriculture fields are to be controlled according to their water use. If pressure sensors are used in the existing pipelines of watering systems data can be gathered about the operation of the system.

In this work we present the experimental system design for remote monitoring the pressure of a watering and gas pipeline system. The idea is to investigate the possibilities to support farmers and organizations involved in continuous monitoring and operation of water and gas pipelines. The novelty of this work is in two aspects: first it uses pressure information to both control the performance in the systems and discover leaks and failures; a new, simple but very efficient static cluster tree routing protocol is defined and experimentally tests that can be used with such systems.

From here on the paper is organized as follows: in the next section we outline the characteristics of similar projects done before. In Section III, the developed system is described. In Section IV, we concentrate on the tested and the experimental results, and in Section V, we conclude the paper.

II. RELATED WORK

Min Lin et al. [1], suggested an interesting application for wireless sensor networks, specifically a water distribution network monitoring system. They propose a possible communication model for the water distribution monitoring network, and describe the channel measurement approach for the determination of an appropriate path-loss model. The accuracy of the proposed measurement approach has been confirmed using the flat earth two-ray model [1].

Yiming Zhou et al. [2], proposed a wireless solution for intelligent field irrigation system dedicated to Jew's-ear planting in Lishui, Zhejiang, China, based on ZigBee technology. Instead of conventional wired connection, the wireless design made the system easy to install and maintain.

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The hardware architecture and software algorithm of wireless sensor/actuator node and portable controller, acting as the end device and coordinator in ZigBee wireless sensor network respectively, were elaborated in detail.

Yunseop (James) Kim et al. [3], describe details of the design and instrumentation of a wireless sensor network for variable rate irrigation and software for real-time in-field sensing and control of a site-specific precision linear-move irrigation system. Field conditions were site-specifically monitored by six in-field sensor stations distributed across the field based on a soil property map, and periodically sampled and wirelessly transmitted to a base station. An irrigation machine was converted to be electronically controlled by a programming logic controller that updates geo referenced location of sprinklers from a differential Global Positioning System (GPS) and wirelessly communicates with a computer at the base station. Communication signals from the sensor network and irrigation controller to the base station were interfaced using low-cost Bluetooth wireless radio communication. Graphic user interface-based software was developed.

Ivan Stoianov et al. [4], discuss how wireless sensor networks can increase the spatial and temporal resolution of operational data from pipeline infrastructures and thus address the challenge of near real-time monitoring and control. They focus on the use of WSNs for monitoring large diameter bulk-water transmission pipelines. They outline PipeNet, a system they have been developing for collecting hydraulic and acoustic/vibration data at high sampling rates as well as algorithms for analyzing this data to detect and locate leaks. Challenges include sampling at high data rates, maintaining aggressive duty cycles, and ensuring tightly time synchronized data collection, all under a strict power budget. They have carried out an extensive field trial with Boston Water and Sewer Commission in order to evaluate some of the critical components of PipeNet.

Liting Cao et al. [5], a remote real time AMR (Automatic Meter Reading) system based on wireless sensor networks is presented. The useful remote AMR sensors are analyzed and an efficient wireless network structure is suggested. The remote measurement system for water supply is taken as a typical example in their experiments. The structure of system employs distributed wireless sensors and consists of measure meters, sensor nodes, data collectors, server and a wireless communication network.

In their work Baoding Zhang et al. [6], introduce a design schema of wireless smart water meter based on the study of existing water meters. The main communication is based on Zigbee. The design is appropriate for modern water management and the efficiency can be improved.

Most of the studies mentioned above imply limited flexibility and reconfigurability. They are expensive to develop since they do not use off-the-shelf solutions to implement wireless sensor networking in a power-efficient and user-friendly way. With the proliferation and standardization of wireless sensor devices the trend is towards simpler and much cheaper solutions based on standardized nodes and networks.

In this study, pressure sensors and IEEE 802.15.4 compliant wireless modules are used to implement a mesh network and water distributing pressure data are stored and displayed on a PC connected to local gateway or base station. The proposed system has the advantage of simplicity, scalability and modularity over other alternatives. It is fully based on off-the-shelf components and freely available hardware and allows easy and reasonably priced setup and tailoring [7, 8]. Even though very similar in principle to others described in literature, our system is more robust, more cost effective and the provided user interface is more elaborate and flexible.

III. SYSTEM DESCRIPTION

A. *System architecture*

A conceptual view of the system is shown in Fig. 1. Each TelosB mote is connected to a remote monitoring system, which allows the observer to track the pressure. The readings are transmitted wirelessly from the specific points on the pipelines through an infrastructure of routing nodes to a central monitoring system (the base station). Depending on the pipeline's distance from the base station, messages can pass through multiple nodes to reach the base station. The base station is connected to a host computer running Moteiv Trawler to interpret, store and display the collected data. There are three main subsystems involved: wireless network structure, data measurement subsystem and the base station with its graphical interface.

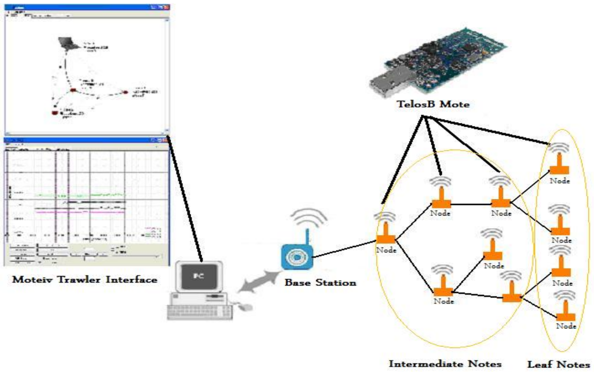


Figure 1. General System Architecture

B. *Freescale Mp3v5050gp Pressure Sensor*

The MPxx5050 [9] is a family of pressure sensors integrating on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. (Fig. 2)

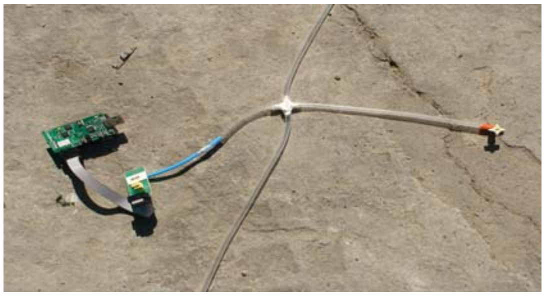


Figure 2. Mp3v5050gp Pressure Sensor Connected to TelosB Mote

C. *Wireless Module and Software*

This wireless communication platform uses TelosB wireless motes programmed in nesC and the Freescale Mp3v5050gp sensors are externally connected to the motes for collecting pressure data from the selected points on the pipelines that is to be transferred to a central database over 802.15.4 based wireless network. The major reason for choosing TelosB, off-the-shelf wireless module, is the ease of programming as well as the low power consumption. The software platform is based on TinyOS [10], an open-source operating system designed for wireless embedded sensor networks and the motes are programmed using nesC, an extension of C. It features a component-based architecture, which enables rapid implementation while minimizing code size [11].

IV. TESTBED SETUP AND EXPERIMENTAL RESULTS

A. *Prototype System Description*

The architecture described above has been implemented and tested in real environment. The network structure is a static hierarchical tree where the motes are mounted on predefined places on the pipes. Such deployment allows for collecting data from specifically selected points as well as precise location of problems. There are two types of nodes defined based on their functionality: leaf nodes and intermediate (collector) nodes. (Fig. 1) Leaf nodes transmit only readings from their own sensors while intermediate nodes transmit both their own and other nodes information doing aggregation when necessary. The base node collects all the data and transfers it to the PC via USB.

The network topology is static hierarchical tree and is given on Fig. 3. Dark colored nodes are leaf nodes, red colored nodes are intermediate nodes doing aggregation and the blue one is the base node. Both leaf and intermediate nodes do sampling and threshold comparison but while leaf nodes transmit only their own data, intermediate nodes also transmit data from other nodes and if necessary do aggregation. The base node does not do any sampling but only transmits collected data.

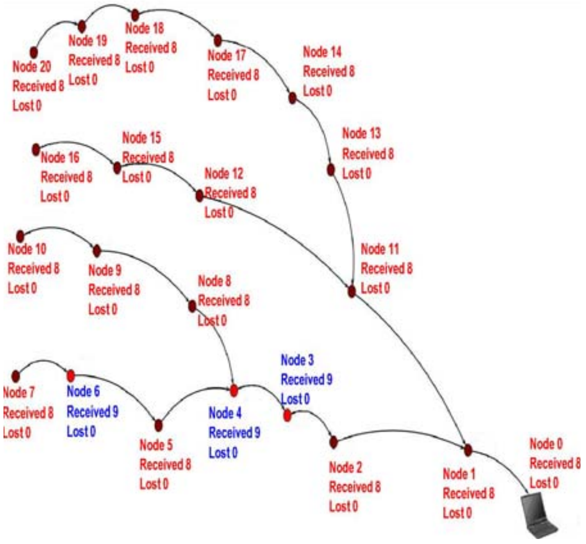


Figure 3. Schematic Network Tree Topology

As it is well known a major source of energy depletion for a wireless node is receiving and transmitting. In order to prevent this and provide longer lifetime two thresholds were introduced. As long as the sensor readings stay within these thresholds the node would be sending data at longer intervals (1 – 2 min). However, as soon as the reading falls outside these thresholds the data is transmitted in an order of seconds. A flow chart of the protocol operation is provided in Fig. 4.

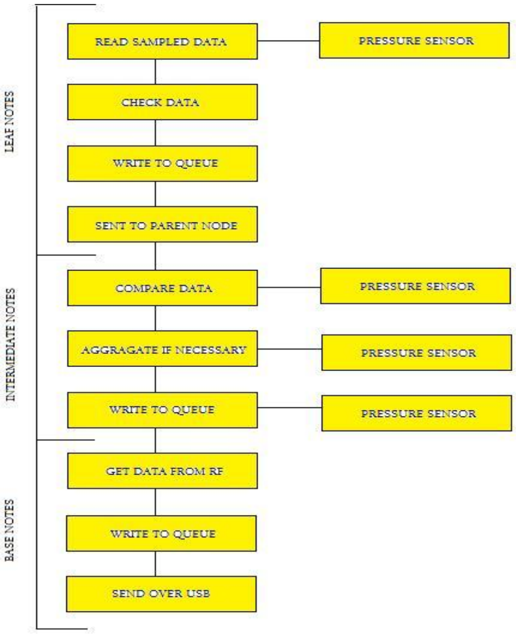


Figure 4. Flow Chart of the Network Protocol

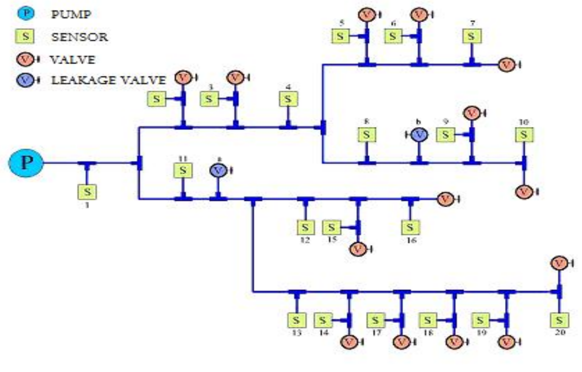


Figure 5. Schematic Deployment Plan

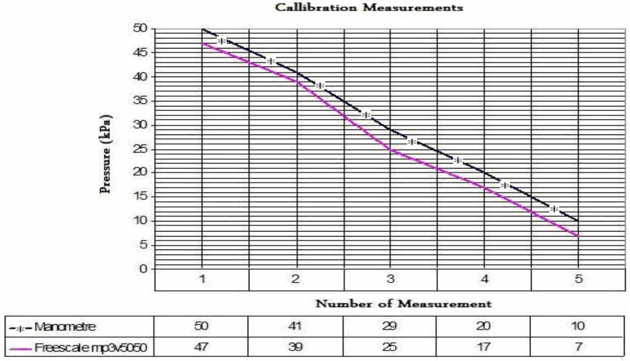
For safety reasons test were done using pressurized air instead of gas or water. The test setup included 20 sensors and 20 nodes plus the base node, equipment for providing pressurized air and plastic pipes as well as equipment to simulate user connection points (marked in red) and controlled pressure leaks (marked in blue). Schematic deployment plan is provided on Fig. 5. Additional filter elements (including a low pass filter) were used in the connection of the sensors to the TelsoB motes.

The test setup covers an area of approximately 200 m^2 with motes placed at distances from 1.5 to 5 m apart. In reality this will represent a very small farmer's field.

B. Testbed Setup and Operation

Using this experimental setup three groups of tests were carried out: calibration tests, user oriented tests and network performance tests. Calibration tests were carried out with the aim to prove the correctness of the pressure samples taken. User oriented tests were carried out to verify the correctness of the collected data as well as the system's proper operation related to the two threshold and its ability to diagnose leakage and other problems.

1) System Calibration: Before testing the performance of the system in real time the pressure sensor measurements were compared with analog manometer measurements. Results are given in Fig. 6. and show a constant minimal difference of 3 kPa which is due to the analog nature of the manometer. As the difference proved linear and quite small it was assumed that it does not influence the performance of the system.



	1	2	3	4	5
Manometre	50	41	29	20	10
Freescale mp3v5050	47	39	25	17	7

Figure 6. Callibration Measurements

2) User Oriented Tests: These set of measurements aimed to test the general user perceived performance of the network. Using the additionally mounted equipment, different users' behavior (different water usage) and unwanted leakage were simulated.

3) Network Performance Tests: In this group of tests the basic performance of the network protocol was tested. Measurements provided information for the packet loss as a function of the duty cycle, packet queue length, distance and load (number of packets per unit time).

Furthermore, the lifetime of the network was evaluated as a function of the duty cycle, the distance and the load distribution. Measurements of the node's energy consumption were taken under different circumstances and lifetime calculations were provided. This allowed us to determine the nodes which are critical from power consumption point of view. Such information is very important and can be utilized at deployment time to overcome possible operational problems or to provide for maximizing the lifetime of the network as a whole. On the other hand, the energy required for the transmission of a single packet was also calculated.

As a result, the performance of the designed protocol can be optimized further to provide better performance once the system is realized at large scale.

C. Evaluation of the Results and Discussion

Evaluation of the results is done form the point of view of the user (pressure information) and the point of view of the network performance (network performance parameters).

1) Correctness of Pressure Data: As for the correctness of the collected information the measurements both in between the two thresholds and outside the thresholds proved that the node data algorithms are working properly. Data related to the time for reporting a possible pressure leak is given as an example in Fig. 7. and Fig. 8. The first one presents the information from all the nodes, while the second one (a zoomed version) shows more clearly the difference in the pressure and the time delay between the two nodes – node number 10 and node number 20.

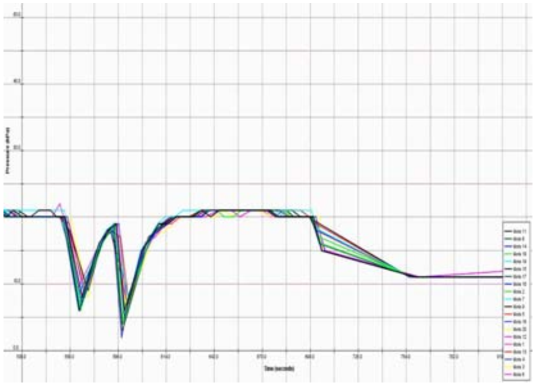


Figure 7. Graph of Changes Pressure Changes for Different Nodes

In Fig. 8. each different color represents and different node. Because the size of the experimental setup is quite small there is a very small time and pressure difference between the nodes (Δt and Δp in Fig. 8). In a larger system these changes will be more easily perceived but still within the limits required for proper reaction.

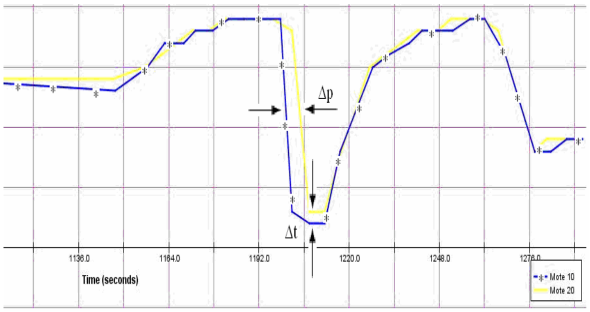


Figure 8. Zoomed Version Showing Two Separate Nodes

These tests and results prove that the suggested system can be used for monitoring a watering system and collecting information about possible leaks in due time. It can be easily attached to an automatic actuator system that will react to such failures and provide automatic closing of certain valves in order to prevent water waste.

2) Network Performance Evaluation: As mentioned above a number of different tests were carried out, however due to space limitations only some are presented here: the packet loss as a function of the sampling period, the length of the queue and the distance; the power consumption as a function of the sampling period as well as the graph of the power consumed by different nodes for a fixed sampling period.

The sampling period is an important parameter which influences both the correctness of the results, the network load and the overall lifetime of the system. Increasing the sampling period reflects in changing the network load – if we assume a 28 bytes packet size, for a sampling period of 1 second the load will be 560 bytes/sec while for a sampling period of 60 seconds it will be 9.3 bytes/sec. Thus, as it can be seen from Fig. 9. and Fig. 10. regulating the sampling period is an important tool in reducing the packet loss and also determining the power consumption. Voltage reduction is the difference between the battery level at the beging and at the end of the experiment. It is important to note that the largest change in power consumption is observed for very small intervals and a decision of interval duration of 2 or 10 sec can drive the required voltage from 0.157 V to 0.0182 V, or nearly 8.7 times less while at the same time packet loss is increased 2.6 times.

Furthermore, measurements in the battery loss for a sampling period of 60 sec show very distinctly (Fig. 11) that due to the hierarchical tree structure some nodes deplete their energy at a much faster rate then others. As these are usually key intermediate nodes, a possible solution is providing alternative energy sources or recharging probabilities, like for example solar rechargeable batteries. Such solutions are still expensive and our study gives an opportunity to evaluate more realistically the need for such implementations. According to our calculations, for the worst case, if a sampling period of 60 sec is applied the TelosB nodes will be able to work for 190 days.

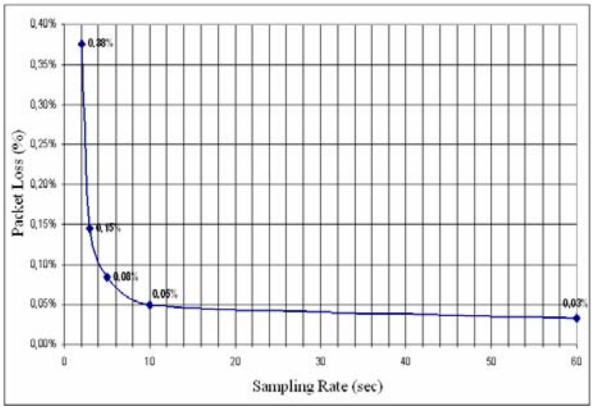


Figure 9. Packet Loss as a Function of Sampling Rate

Another factor which can be regulated to tune the network performance is the length of the queue of packets to be sent (or in other words the sending buffer size). For example, for a queue length of packets per node 7 the packet loss is 0.017% compared to 0.195% for a length of 2 packets. We have also observed that 7 is an optimal value since an increase to 8 o9 has also leaded to increase in the packet loss to 0.043 (Fig. 12).

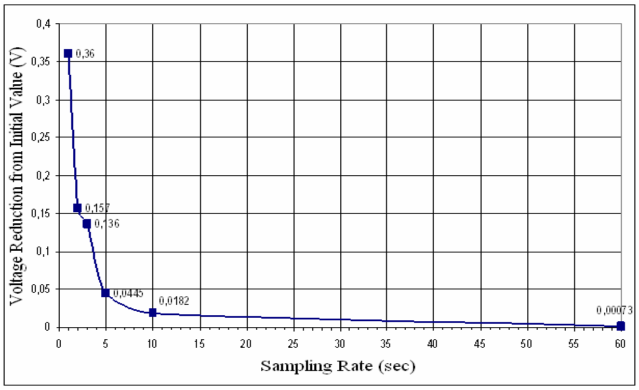


Figure 10. Voltage Reduction as a Function of Sampling Rate

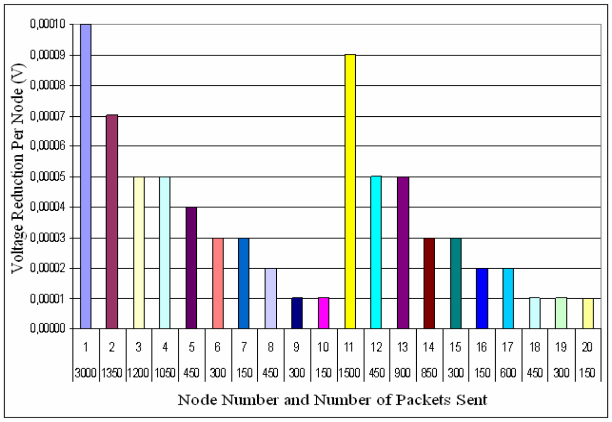


Figure 11. Voltage Reduction Per Node for 60 sec. Sampling Rate

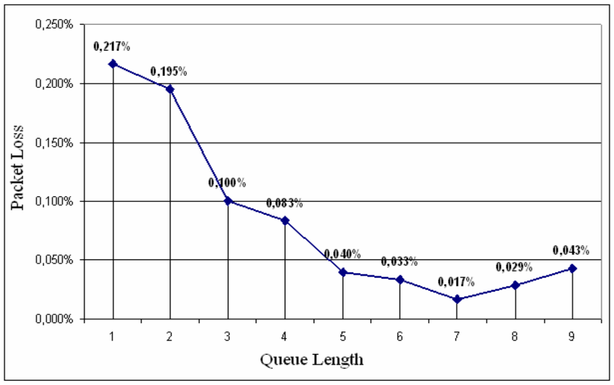


Figure 12. Packet Loss as a Function of Queue Length

Finally, the packet loss as a function of the distance between nodes is presented in Fig. 13. According to the datasheets TelosB modes have a range of up to 125 m. However our tests, done in the open field have shown that at a distance of 120 m the packet losses are unacceptably high (nearly 60%). Accordingly, packet losses less than 2% can be achieved if the nodes are deployed at up to 70 m apart.

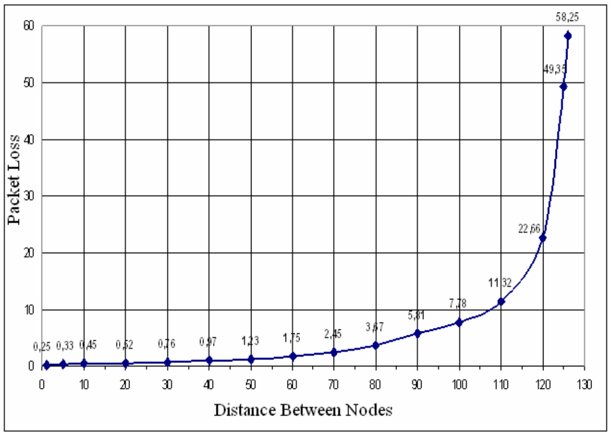


Figure 13. Packet Loss as a Function of the Distance Between Nodes

V. CONCLUSION

In this study, we have presented the design considerations and results from the experimental prototype of a wireless sensor based network for collecting pressure data that can be used for watering systems and gas pipelines. The system is based on TelosB motes organized in a WSN with a suitable designed network protocol which provides also data control and aggregation. The field-tests aim to provide insights into the possibilities for optimizing the network performance and increasing the network lifetime as a whole. The prototype is based on requirements provided by the 2nd DSI (2nd Regional Directorate of State Hydraulic and Water Works) for a water project in Usak, Turkey.

This theoretical and experimental work will provide an example of the possibilities to apply WSN for better and more effective control and implementation of farming watering systems. Such systems are static and the selected hierarchical tree network architecture and the pertinently designed protocol provide both very effective use of network resources and possibilities for fast determination of leaks and problems. The performance of the network and its power consumption were examined in detail and the parameters and methods to increase both its performance and lifetime were outlined. To reduce traffic load data aggregation and sampling rate optimization was suggested. Due to the adopted addressing scheme the coordinates of the problems can be efficiently determined without the need of GPS data.

In the future the system can be further enhanced by connecting to an actuator network that will provide timely reactions to prevent water waste.

As a result, the work presented in this paper provides the background for further research and implementation of wireless sensor networks is agriculture related fields as automatic watering systems. With small adjustments and additions the suggested system can be used for gasoline pipeline monitoring and control as well.

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