Design and Performance Analysis of Building Monitoring System with Wireless Sensor Networks

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Abstract
The Wireless Sensor Network (WSN) provides a potential technique for monitoring the indoor environment. The proposed system consists of several wireless sensor nodes that are deployed in a building in addition to a local server hosting web base application for storing sensing data. The widely adopted standard for wireless sensor network platform is the IEEE 802.15.4/ ZigBee. It is considered as the “technology of choice” due to low-power, cost-effective communication and the reliability it provide. This paper will simulate and explore the performance of ZigBee using OPNET Modeler 14.5. The paper will study and analyze various parameters that include changing the network topology, number of nodes and different performance parameters such as network delay, throughput, and others. The web base application is designed to interact with a WSN, allowing a user to consult sensor states and receive sensor alerts. Sensor alerts will be received when a sensor's threshold value exceeds the limit. Therefore, the user will be notified whenever there are changes in the WSN. The web base application system allows the manager or owner of building to remote monitoring sensing data via Internet by using a web browser.
Keywords: Building Monitoring System, Wireless Sensor Networks, ZigBee.

تصميم وتحليل أداء نظام مراقبة المبنى مع شبكات الإستشعار اللاسلكية

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الخلاصة
إن شبكات الاستشعار اللاسلكية توفر تقنية ممكنة لمراقبة البيئة الداخلية. ان النظام المقترح يتكون من عدة عقد استشعار لاسلكية توزع في البناية بالإضافة إلى خادم محلي يستضيف تطبيق الويب لتخزين بيانات الاستشعار. إن المعيار المستخدم بصورة واسعة لشبكات الاستشعار اللاسلكية هو الزكبي (IEEE802.15.4 / ZigBee). حيث يعتبر هذا المعيار "التكنلوجيا المختارة" لما يوفره من استهلاك قليل للطاقة، فعالية من حيث تكلفة الاتصال و الموثوقية. هذه الدراسة تحاكي وتكشف أداء هذا المعيار (ZigBee) باستخدام برنامج (OPNET Modeler 14.5) إضافة إلى دراسة مجموعة مختلفة من المعاملات تتضمن تغيير طوبولوجيا الشبكة، عدد العقد ومقاييس أداء مختلفة مثل تلكؤ الشبكة، كمية نقل البيانات، وغيرها. لقد تم تصميم تطبيق الويب ليتفاعل مع شبكات الاستشعار اللاسلكية، سامحاً للمستخدم معرفة حالة العقد واستلام تنبيه الاستشعار. إن تنبيه الاستشعار يستلم في حالة تجاوز قيم الاستشعار تتجاوز القيمة المحددة أو الطبيعية،وعند ذلك يتم تبليغ المستخدم متى ما يحدث تغيير على شبكات الاستشعار اللاسلكية. كذلك فأن تطبيق الويب سيسمح لمدير أو مالك البناية مراقبة بيانات الاستشعار عن بعد عن طريق الانترنت باستخدام متصفح الويب.

1. Introduction

Future buildings will be smart to support personalizedpeople comfort and building energy efficiency as well assafety, emergency and context-aware information exchanges cenarios [1].
Accurate monitoring of the buildings, systems and their surroundings has normally been performed by sensors dispersed throughout the buildings. Existing building systems are tightly coupled withthe sensors they utilize, restricting extensibility of their overall operation[2].
Wired sensors should setup at sensing positions, but this requires a lot of effort and an additional set of wires inside building. Also estimation cost to install wires ranged from 2.2$ per meter for new buildings to 7.19$ per meter for existing buildings[3]. To pass these drawbacks Wireless Sensor Networks (WSN) can be used. Its consist of light-weight, low-power and small size sensor nodes (SNs). They have the ability to monitor, calculate and communicate wirelessly. The development of this technology is supported by advancement in electronic miniaturization (including microelectromechanical system (MEMS) technologies)[4].
ZigBee is an efficient wireless standard that gives reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard[5].
In this paper, the OPNET modeler V (14.5) is used to simulate the performance of several wireless network topologies [6].
The rest of this paper is organized as follows. Section (2)presents an overview of Wireless Sensor Networks. Section (3)presents a standard Overview of WSN. Section (4) presents ProposedSystem Design. Section (5) presents results obtained from some studies and Section (6) is the Conclusions.

2. Wireless Sensor Networks (WSNs)

Wireless Sensor Networks (WSNs) have been widely considered as one of the most important technologies for the twenty–first century. Enabled by recent advances in microelectronicmechanical systems (MEMS) and wireless communication technologies, tiny, cheap, and smart sensors deployed in a physical area and networked through wireless links and the Internet provide unprecedented opportunities for a variety of civilian and military applications[7].
WSNs are composed of individual embedded systems that are capable of interacting with their environment through various sensors, processing information locally, and communicating this information wirelessly with their neighbors[8].
Existing and potential applications of sensor networks include, military sensing, physical security, air traffic control, traffic surveillance, video surveillance, industrial and manufacturing automation, process control, inventory management, distributed robotics, weather sensing, environment monitoring, national border monitoring, and building and structures monitoring[9].

3. Standard Overview

To facilitate the worldwide development and application of WSNs, there is a need for building a large low - cost market for sensor products in the field. For this purpose, it is important to specify relevant standards so that sensor products from different manufacturers may interoperate.
The IEEE 802.15.4 is a standard developed by IEEE 802.15 Task Group 4, which specifies the physical and MAC layers for low - rate WPANs. The goal of Task Group 4 is to "provide a standard for ultralow complexity, ultralow cost, ultralow power consumption, and low - data rate wireless connectivity among inexpensive devices".
The ZigBee standard is developed on top of the IEEE 802.15.4 standard and defines the network and application layers. The network layer provides networking functionalities for different network topologies, and the application layer provides a framework for distributed application development and communication[7].

3.1. ZigBee Specifications

The core ZigBee specification defines ZigBee's smart, cost-effective and energy-efficient mesh network. It is an innovative, self-configuring, self-healing system of redundant, low-cost, very low-power nodes that enable ZigBee's unique flexibility, mobility and ease of use.

3.2. ZigBeeTopologies

IEEE 802.15.4 supports three types of topologies: Star, Mesh and Tree (that can be considered as a special case of Meshtopology) as shown in figure (1).

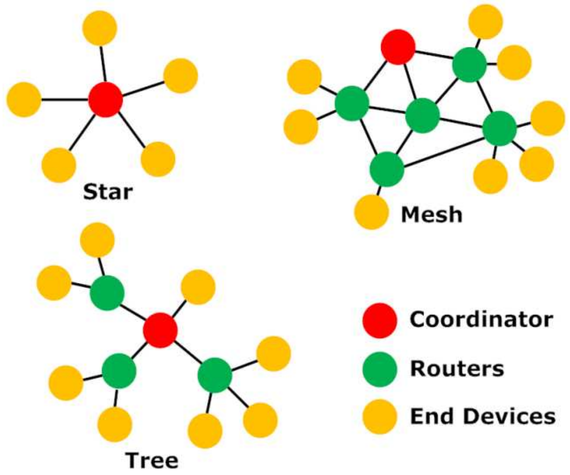

Figure 1-Zigbee Based Network Topologies

a) Star Topology

In this simple topology, a coordinator is surrounded by a group of either end devices or routers. This type of topology is attractive because of its simplicity, but at the same time presents some key disadvantages. In the event that the coordinator stops functioning, the entire network is functionless because alltraffic must travel through the center of the star. For the same reason, the coordinator could easily be a bottleneck to traffic within the network, especially since a ZigBee network can have more than 60000 nodes.

b) Tree Topology

In a tree network, a coordinator initializes the network, and is the top (root) of the tree. The coordinator can now have either routers or end devices connected to it. For every router more child nodes can be connected to the router. Childnodescannot connect to an end device because it doesnot have the ability to relay messages. This topologyallows for different levels of nodes, with thecoordinator being at the highest level. For messages tobe passed to other nodes in the same network, thesource node must pass the message to its parent, which is the node higher up by one level of the source node, and the message is continually relayed higher up in the tree until it can be passed back down to the destination node. Because the number of potential paths a message can take is only one, this type of topology is not the most reliable topology. If a router fails, then all of that router's children are cut off from communicating with the rest of the network.

c) Mesh Topology

A mesh topology is the most flexible topology of the three. Flexibility is present because a message can take multiple paths from source to destination. If a particular router fails, then ZigBee'sself healing mechanism (route discovery) will allow the network to search for an alternate path for the message to take. This mechanism will be discussed in section 5.3 of paper.

4. Proposed System Design

A proposal for a building monitoring system that can remotely monitor the sensing data via Internet can be shown in figure (2). This system consists ofseveral wireless sensors that deployed in monitoring area (Building), Web server contains sensing data, and remote user for monitoring these data via Internet using web browser.

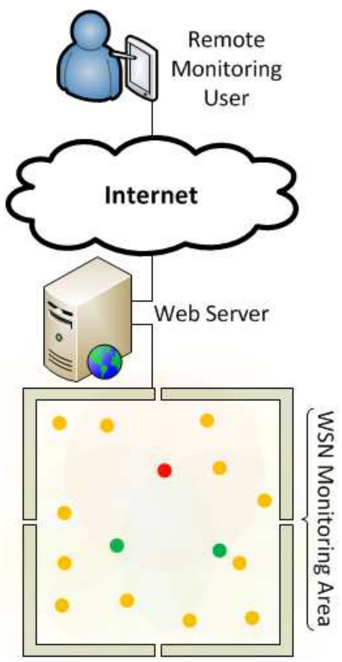

Figure 2- Proposed Architecture Of Building Monitoring System

5. Simulation Results of Some Case Studies

The actual building of the senior staff / Information Engineering College in Al-Nahrain University was chosen with (20m×20m) dimensions and three floors to implement this study. Different topologies will be applied, ineach type of topologies (Star, Tree, and Mesh) three scenarios will be used with variable numbers of end devices. Table (1) shows thesimulation parameters in each topology.

Table 1- Simulation Parameters

	Star	Tree	Mesh
Coordinator	1	1	1
Router	0	3	3
No. of End devices	15, 30, 45	15, 30, 45	15, 30, 45
ACK	Enabled	Enabled	Enabled
CSMA-CA	Enabled	Enabled	Enabled
Packet size	1024 bits	1024 bits	1024 bits
ISM band	2.4 GHz	2.4 GHz	2.4 GHz

The application traffic is to all nodes for coordinator and to coordinator for other nodes. The time of simulation is 600 seconds.
The end devices are randomly distributed in the rooms of each floor for monitoring the equipments and environments of these rooms. One router can be deployed on each floor in the case of Tree and Mesh topologies for routing packet. Figure (3) shows the implementation of different topologies and distribution of nodes in a 3D building.

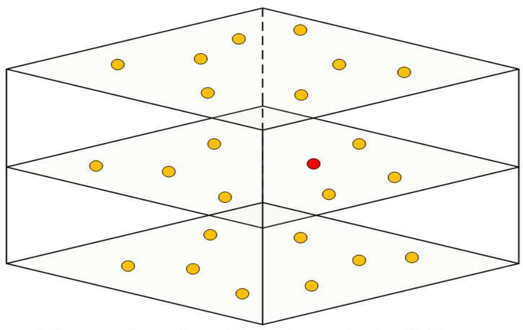

Figure 3a- Star Topology in building

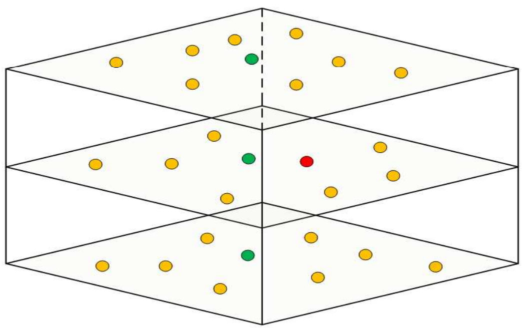

Figure 3b- Tree and Mesh Topology in building

Figure 3- Topologies In A 3D Building

5.1 End-to-End Delay

End-to-end delay is the measurement of total network delay between creation and reception of an application packet.
Figures 4(a, b, and c) shows the end-to-end delay in seconds for different topologies and variable number of nodes. Figure (4a) for 15 nodes, figure (4b) for 30 nodes, and figure (4c) for 45 nodes. Star topology has the minimum end-to-end in these cases; because it has the minimum number of hops to reach destination, While the tree and mesh topologies have nearly a close values of end-to-end delay.

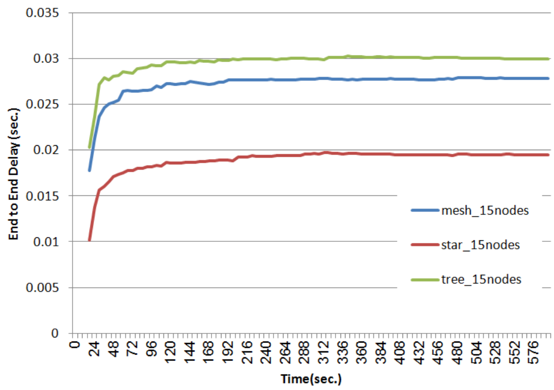

Figure 4a- End-To-End Delay Of 15 Nodes

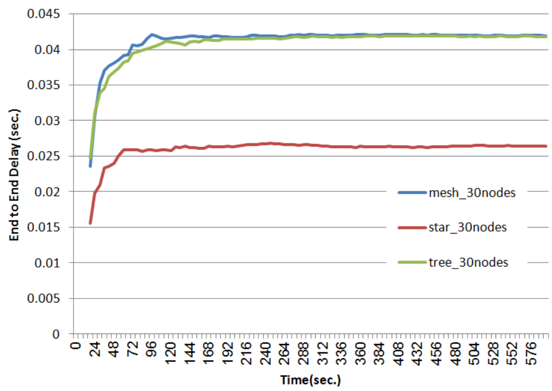

Figure 4b- End-To-End Delay Of 30 Nodes

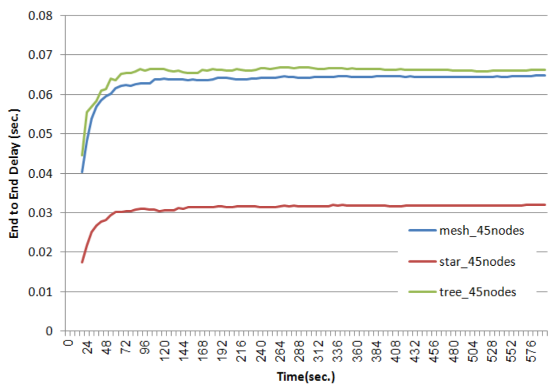

Figure 4c- End-To-End Delay Of 45 Nodes

5.2 Throughput

It is a Coordinator MAC throughput, Represents the total number of bits (in bits/sec) forwarded from 802.15.4 MAC to higher layers in coordinator node.

Figures 5(a, b, and c) shows the Coordinator MAC throughput in (bits/sec.) for different topologies and variable number of nodes. Apparently the Coordinator MAC throughput increased when the number of nodes increases. This is true because the data are received by the MAC layer increases.

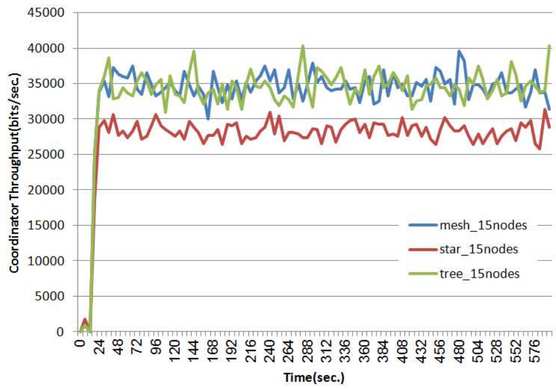

Figure 5a- Coordinator Throughput Of 15 Nodes

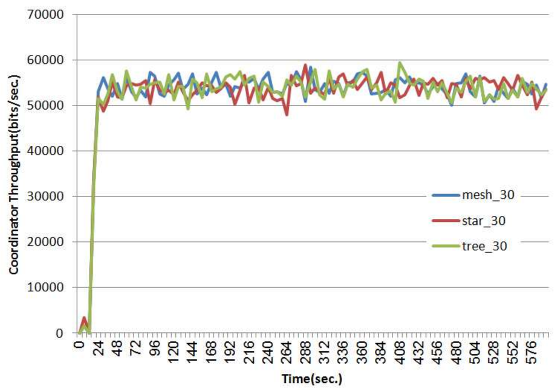

Figure 5b- Coordinator Throughput Of 30 Nodes

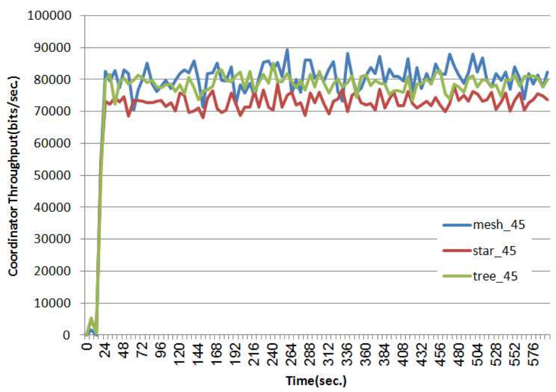

Figure 5c- Coordinator Throughput Of 45 Nodes

5.3 Self Healing Mechanism

As shown in figure (3b) tree and mesh topologies have the same structure except that mesh topology has self healing mechanism also known as route discovery.

In order to show this mechanism the comparison should be made between tree and mesh in case of one router fail and illustrate how this fail can affect the average MAC throughput.

Figure (6a) shows the failure of router 1 at 200 second in tree topology. This failure affect the average throughput of tree because every nodes connected to router (1) are disconnected from entire network.

Figure (6b) shows the same failure but in mesh topology. This failure doesn't affect the average throughput of mesh because every nodes connected to router (1) will try to find an alternative path for connecting to the network.

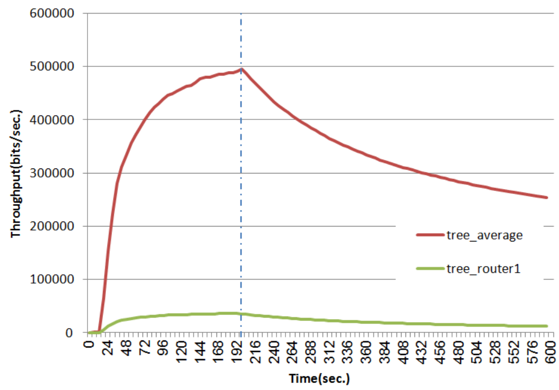

Figure 6a- Failure In Tree Topology At 200 S.

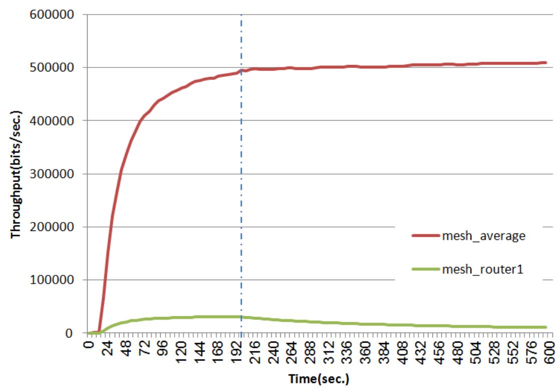

Figure 6b- Failure In Mesh Topology At 200 S.

6. Conclusions

In this paper the architecture of building monitoring system with wireless sensor networks (WSNs) is proposed.

Different topologies and nodes are simulated in this system lead to many results helping the engineers to decide which suitable topology should be used. This decision also depends on the type of monitoring application inside the buildings.

Some application needs lower end-to-end delay as much as possible and others need self healing mechanism etc.

In the future works, we plan to implement a test bed for this system using wireless sensor hardware based on ZigBee standard and analysis sensing data in web server.

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