Energy-Aware Routing Architecture for Wireless Sensor Networks

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***Abstract*— The resources used for WSNs are typically limited, and it is essential for these limited resources to be used effectively within scope of the architectural structure. This study suggests an efficient routing architecture. Two environments, consisting of a simulation program and an experimental set, were used in order to demonstrate the performance offered by the suggested routing architecture. The first step to developing applications on WSNs is acquisition of results through implementation of the work on a simulation program. Following a successful outcome from the work carried out on the simulation program, it is essential for the system to be tested on an experimental set in order to confirm the validity of the results. The accuracy of the results yielded by the suggested routing architecture's design is tested in two stages. The first stage involves acquisition of results through the experimental setup. The second stage consists of acquisition of simulation program results for the same number of nodes, followed by a comparison of both result sets.**

Keywords*— *wireless sensor network, energy awareness, routing architecture

I. INTRODUCTION

A WSN (Wireless Sensor Network) can be defined as a network consisting of scattered devices and is used to cooperatively monitor the physical or environmental conditions (such as temperature, sound, pressure, movement, pollution, etc.) at different locations [1-2-3]. WSNs can be implemented in numerous environments such as military security zones, natural habitats, homes and offices, and the portable and lightweight design of the sensors makes it possible for WSNs to be used in different areas such as medicine as well [4]. In these networks, each sensor that is scattered in a certain area has the capacity to collect data and route it to a specific target. The data that is sent to the target sensor can be analyzed therein or sent to remote points via internet and satellite connection.

The very first examples to WSNs came into being with military research in the early 1950s. [5]. The concept of WSN (Wireless Sensor Network) first appeared in the early 1980s. In 1990s, along with the development in wireless communication systems, WSNs started to become an important area of research [5]. From the early 1980s to the 1990s, WSNs integrated within ground-based surveillance systems and AWACS systems (also known as airborne warning and control systems) were used for air surveillance, control and communication while the radars on AWACS aircraft enabled detection of distant moving targets. [6]. Another invention created using WSNs is the Air Delivered Seismic Intrusion Detector (ADSID) system, which was developed by the US Air Force to be used during the Vietnam War. In this system, sensors deployed along the route detect the vibrations from moving objects and relay these to the recipient aircraft [5]. High power consumption, heavy weight and a lifetime of a few weeks are considered to be the most important disadvantages of the first WSN applications [7]. These networks, which were primarily used in the military, came to have a much larger area of use as the costs decreased and the sensor capabilities increased in line with technological advancement [1]. Invention of the low power wireless integrated micro sensors (LWIMs) by UCLA and Rockwell Science Center in 1996 brought along the commercial use of wireless sensors [7]. In 1998, UCLA and Rockwell Science Center went on to create the second generation sensor nodes referred to as Wireless Integrated Network Sensors (WINSs) [7]. WINSs contain a radio card and sensor card which support 100 Kbps wireless communication with a power consumption that can be adjusted with a range of 1 to 100 mW [8]. In 1999, the sensor node referred to as WeC was created within scope of the Smart Dust project developed by UC Berkeley. WeC contained an Atmel Microcontroller (512 B RAM, 8 KB Flash Memory) with an active power consumption of 15 mW and passive power consumption of 45 µW at 8-bit 4 MHz speed. Furthermore, WeC supported wireless data communications at a speed of 10 Kbs with a power consumption of 36 mW for the transmitter and 9 mW for the receiver [9]. In 2001, use of the Mica product family consisting of the Mica, Mica2, Mica2Dot and MicaZ product groups began. [10]. This was followed by use of the Mica2 and Mica2Dot nodes together with the ATmega128L microcontroller with an active power consumption of 33 mW and passive power consumption of 75 µW in 2002 [11]. This module also supported integrated encryption and authentication. Another product by Motes, referred to as Telos, was created in 2004 [11]. Telos, which uses a microcontroller from Texas Instruments with an active power consumption of 3 mW and passive power consumption of 15 µW, stands out with significantly low power consumption. [10]. In 2002, CENS (Center of Embedded Networked Sensing) developed the sensor node Medusa MK-2. Combination of these two microcontrollers with different properties gave WSNs versatility for use in environments requiring high speed and long battery life [7]. In 2003, Berkeley Wireless Research Center (BWRC) addressed the significant power consumption issue for wireless nodes by creating PicoBeacon, the first wireless transmitter powered by solar energy and vibration signals. The integrated RF module has a power consumption of less than 400 µW. [12]. An analysis of the research carried out from 2004 to current day reveals an emphasis on smart traffic applications developed to provide time and fuel efficiency [14], smart city applications developed to prevent noise and pollution as well as enable waste control through tracking [15], applications developed

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for control of agricultural land and greenhouses, and research on use of solar energy to improve the service life of WSNs [15].

There are numerous studies for efficient use of energy in WSNs. These consist of studies for increasing hardware resources and studies that focus on the architectural structure [16]. Identifying the areas of energy consumption in WSN infrastructure and, as a result, the areas to focus on for improvement is of vital importance in order to conduct research on efficient energy use [17]. This study will provide information on these areas. The study suggests a routing architecture for WSNs [18]. The most important performance criterion for the verified system was energy efficiency.

II. MATERIAL AND METHOD

The architecture developed within scope of the study was verified in both simulation and experimental environments. A model was created using the Castalia simulator and a Jennic Set for the testing environment. The algorithms developed on the model were tested and the acquired results were checked against the simulation environment for a comparison of the model performance. For the tests carried out in a laboratory environment, it was considered that a network topology was established and a path consisting of 10 sensors (including SN and TN) was assigned as the most suitable one in terms of energy awareness in the path determination phase. In testing environment of 10 sensors, a model of a system consisting of 500 sensors was created along with setup modifications such as different paths, distances, etc. Figure 1 demonstrates the established laboratory setup [15].

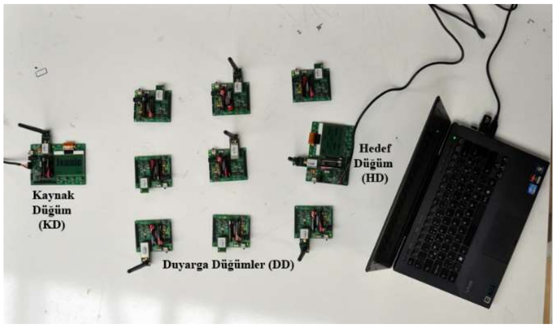


Fig. 1. Laboratory Test Setup

The study puts forward a routing architecture for efficient use of the total network lifetime. The primary goal of the architectural structure is to ensure transmission over the most efficient path for data to be sent to a target node from a source node. The figure 2 shows a network model consisting of 1 source node, 1 target node and 10 carrier sensor nodes. The nodes used in the study have the following properties.

All sensors that are used have the capability to detect temperature, humidity and light.

It is possible to make adapter connections of source and target nodes.

Sensor nodes can be used as routing nodes.

It is possible for the nodes to communicate through RF with connected antennas.

It is also possible to install developed software and algorithms by connecting the nodes to a computer via connection cables. This, in turn, makes it possible to run the algorithms designed on hardware.

The network architecture in question consists of sensor nodes (SEN) placed in an area, the source node (SN) that detects and transmits information, and the target node (TN) in which the measured data is collected.

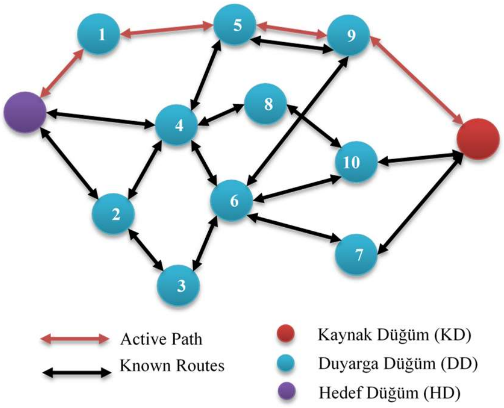


Fig. 2. WSN Network Model

The SN is tasked with conducting detection in the environment and propagating the detected information by relaying it to the TN. The DN, on the other hand, is tasked with storing and processing the incoming data, as well as managing all communication processes on the network. In this doctorate study, the DN is the decision-making mechanism for the entire operation within the network. The duty of the SEN is to serve as a bridge in the process of information transmission from the SN to the DN. In the study, the SENs did not perform any detection work in order for the values concerning energy efficiency to be revealed. The routing architecture designed within scope of this study consists of phases for creating the network topology, determining possible paths, conducting data transmission, eliminating any potential issues and defining the relationship between the phases. The general structure of the routing architecture in this study is shown in the Figure 3.

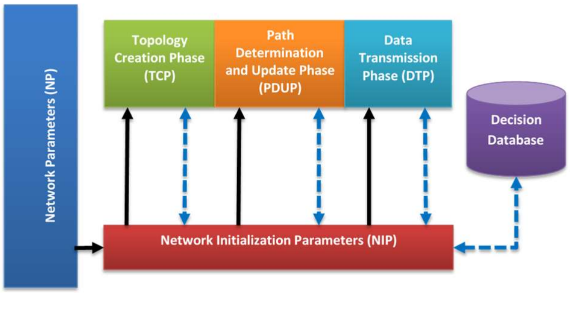


Fig. 3. General Structure of Routing Architecture

The design includes a network initialization parameters (NIP) module for identification of the initialization parameters required by the network topology, a phase for creation of the network topology in the system architectural structure, a phase for determination of the routing paths, a phase for data transmission between the SN and the DN, and a phase for management of the network operation. The phases in question can be briefly described as follows.

Topology Creation Phase (TCP): The phase in which the neighbor relations between the SN and the DN are identified and the paths within the network are determined.

Path Determination and Update Phase (PDUP): The phase in which the paths that are found to be effective in the light of the algorithm suggested in this doctorate study are prioritized to increase the network lifetime according to the path information acquired during the TCP.

Data Transmission Phase (DTP): The phase in which data transmission is carried out via the prioritized path and the processes regarding data transmission are managed.

Network Management Phase (NMP): The phase in which the entire network operation is managed. The processes of all phases in the architecture are controlled through the NMP. All stages that are required for communication are managed by the NMP. The TCP informs the NMP after determining the topology and the NMP initiates the PDUP for path determination. After the PDUP determines the path information, the NMP starts the data communication process with the DTP. The NMP also manages the actions to be taken against any issues that may arise during these stages. While managing the network operation, the NMP utilizes the decision database. The decision database contains the tables required for decision-making by the NMP, such as routing tables and cost tables.

Within the suggested energy-aware routing architecture, the data in all communication processes is carried in message packets between the nodes. In this doctorate study, a message packet structure of minimum size was created to avoid transmission of unnecessary data and the fields of the message packet were used for various goals, depending on the message type. The general message packet structure used to enable communication between the DN and the SN in the design is shown in the figure 4.

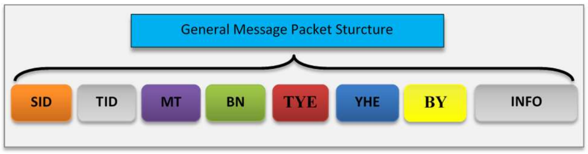


Fig. 4. General Message Packet Sturcture

- The areas used in the general message packet can be described as follows.
- SID: SID is used to identify the source address of the incoming message. SID provides the ID (Identification) number of the node from which the message is sent (also referred to as node number). This field is used in all message types within the architecture.
- TID: TID is used to identify the address of the target node to which the message is sent.
- MT: MT defines the message type used for communication between the DN and the SN. The type of the incoming message and the actions to be taken by the SENs according to the relevant message type is defined within the system architectural structure.
- BN: The BN field defines the bounce number between the DN and the SN, which is the number of SENs used along the path between the DN and the SN. The SS field particularly takes an active role in creation of the energy-aware paths in the TCP module and determination of the path before initialization of transmission in the DTP module. BN is also used as a parameter that limits the lifetime of a package within the WSN. This ensures for excessive energy consumption to be avoided by preventing the package from remaining in the WSN for longer than necessary.
- INFO: Depending on the message type defined in MT, the INFO field can both define the values detected by the SN (temperature, pressure, etc.) and the number of SENs between the DN and the SN. This study assumes that a reasonable number of paths can be transmitted within a data packet. Furthermore, since the data to be sent from the SN to the DN has a small size, it can be relayed to the DN within a single data packet.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The architecture designed for energy-aware routing in wireless sensor networks was tested in both a simulation and an experimental environment. In the study, it was considered that a network topology was established and a path consisting of 10 sensors (including SN and DN) was assigned as the most suitable one in terms of energy awareness in the path determination phase. The study analyzes the impact of data transmission frequency on energy consumption, the impact of bounce number on energy consumption and the impact of sensor node number on the designed energy-aware architecture, and demonstrates the performance of the architecture through a comparison between the experimental environment and the simulation environment.

A. Impact of Data Transmission Frequency and Energy Consumption

Since the final goal for WSNs is successful data transmission, energy spent per unit of successful data transmission is an important parameter. One of the factors affecting transmission success is the transmission frequency of the data acquired from the source node. As clearly seen in the Figure 5, energy consumption increases in direct proportion to data transmission frequency.

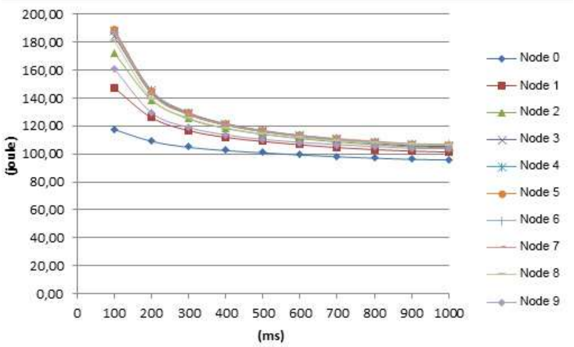


Fig. 5. Model Total Energy Consumption

The Table shows the total energy consumption and success ratio according the varying data transmission frequencies.

TABLE I. DATA TRANSMISSION FREQUENCY / ENERGY CONSUMPTION

Packet Delivery (msn)	Energy Consumption (J)	Total Packet	Successful Packet	Success Rate (%)
s1=100	1713,149	99742	46687	0,468
s2=200	1363,169	49871	29598	0,593
s3=300	1234,858	33247	21494	0,646
s4=400	1170,692	24935	17023	0,683
s5=500	1130,666	19948	14357	0,720
s6=600	1102,347	16623	11966	0,720
s7=700	1080,377	14248	10241	0,719
s8=80	1063,933	12467	8909	0,715
s9=900	1048,161	11082	7943	0,717
s10=1000	1043,527	9974	7118	0,714

An evaluation of the Table and the Figure together reveals a low success ratio in spite of an increase in the packets processed in each node and, as a consequence, the total energy consumption of the nodes when the data transmission frequency rises. Therefore, frequent data transmission increases the energy consumption per successfully relayed data unit. Due to this, identifying the data transmission frequency is important in designing an energy-aware architecture. As seen in Figure 5 and Table I, a reasonable data transmission frequency both increases the performance ratio and decreases energy consumption per node.

B. Impact of Bounce Number on Energy Consumption

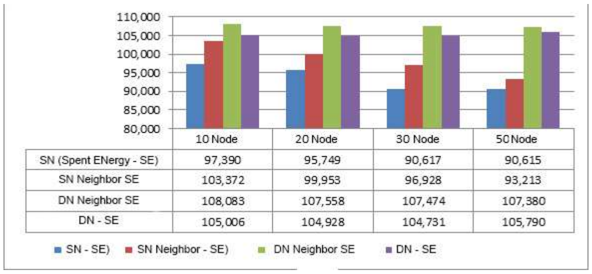
Another parameter affecting the energy consumption per unit of successfully detected information is the number of nodes along the selected path. The Table II shows the total energy consumption in the system and the energy consumption per successful packet according to varying bounce numbers. These results were obtained in the Castalia simulator with a data transmission frequency of 800 ms and a total simulation time of 10,000 ms.

As also demonstrated by the table, energy efficiency in WSNs is dependent on the total bounce number in the selected path. Total energy consumption per successful packet increases exponentially as the bounce number rises. The study shows the justification of using a mechanism that will guarantee minimum energy consumption in the system suggested for energy-aware structure.

TABLE II. TOTAL DATA TRANSMISSION FREQUENCY / ENERGY CONSUMPTION

Number of Nodes	Total Energy (J)	Successful Packet	Total Packet	Success Rate (%)	Energy Per Packet
d2	113,57	12373	12498	0,99	0,07
d5	1055,88	11732	12481	0,94	0,09
d8	1138,72	10352	12472	0,83	0,11
d10	1065,01	8989	12466	0,72	0,12
d20	2141,86	5358	12402	0,43	0,40
d30	3172,71	990	12309	0,08	3,20
d50	5071,69	137	12276	0,01	37,02

As seen in the figure 6, the highest energy consumption occurs in intermediate nodes in spite of the fact that these nodes have limited energy. The algorithm developed for this study attempted to keep the processes per sensor at a low level. Furthermore, it was also revealed during the study that load-sharing for path information in nodes that are close to the target has high importance.



	10 Node	20 Node	30 Node	50 Node
SN (Spent ENergy - SE)	97,390	95,749	90,617	90,615
SN Neighbor SE	103,372	99,953	96,928	93,213
DN Neighbor SE	108,083	107,558	107,474	107,380
DN - SE	105,006	104,928	104,731	105,790

Fig. 6. Highest Energy Consumption of Sensor Nodes

C. Comparison of the Experimental Environment with the Simulation Environment

The experimental setup consists of 10 sensors. In order to acquire realistic results in the laboratory environment, the starting point for this study was the data transmission phase. The configuration of each sensor node was provided with the nodes from which it would receive data and the nodes to which it would transmit data. This guaranteed the bounce numbers in path identification. The results of the experimental environment and the simulation environment, as well as the performance ratios according to varying bounce numbers, are shown in the Table III.

TABLE III. COMPARISON TABLE

Hop Counts (HC)	Simulation Success Rate (%)	Experimental Success Rate (%)
2	0,99	0,98
5	0,94	0,92
8	0,83	0,82
10	0,72	0,70

As seen in the Table III, the results acquired in a laboratory environment are consistent with the results acquired in the Castalia simulator. This outcome constitutes proof that the results acquired in the simulator for the architecture developed during this study is realistic.

D. Impact of Node Number on Architecture

During simulation in Castalia, the data transmission was 800 ms, simulation time was 10,000 ms and the distribution surface was 500 m x 500 m. The table shows in random order the results acquired according to varying numbers of sensors distributed on the surface mentioned above. Since the developed architectural structure involves a minimum number of processes, it is seen that the energy consumption per sensor is almost constant regardless of the number of sensors in the system.

In both simulation and laboratory environments, the study demonstrates success for the algorithms and mechanisms developed within an energy-aware routing structure in wireless sensor networks.

IV. CONCLUSION

The study suggests an architecture which is capable of energy-efficient routing via control of routing processes for WSNs. During the study, a wireless sensor network consisting of a source node, target node and intermediate sensor nodes was created and the performance of the suggested energy-aware routing architecture design for this WSN was demonstrated. The suggested architecture for the WSN involved development of mechanisms via a topology creation phase for discovery of the paths between the SN and the DN, a path determination and update phase for selection of the most effective path in terms of network lifetime among the discovered paths and update of a path that is no longer effective through replacement with a new path, a data transmission phase for data transmission between the SN and the DN, and a network management phase for ensuring coordination with each process. Each mechanism within the system was tasked with reducing energy consumption, keeping energy consumption per successful packet at reasonable levels and increasing network lifetime. The study involves tests in both simulation and experimental environments. These tests were conducted to seek answers to the questions related to the impact of data transmission frequency on energy consumption, the impact of the number of bounces along the path on energy consumption and the impact of the number of sensor nodes within the network on energy consumption. Furthermore, the performance of the developed architectural structure was analyzed in both simulation and experimental environments. An examination of the acquired results revealed the simulation and laboratory environments results for the architectural structure to be consistent and the developed energy-aware routing architecture model to be capable of guaranteeing minimum energy consumption.

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