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Energy-Aware Communication Strategies for Wireless Sensor Networks in IOT Applications

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Abstract
This paper describes energy-aware communication strategies for wireless sensor networks (WSNs) in IoT. The IoT system depends on the power and whenever we attach the number of sensors the power consumption increases and the life time of the total system decreases if the usage of the system maximum. The main focus is on maximizing network span by efficiently managing energy consumption. The detailed study which involves modeling energy harvesting, communication power consumption, dynamic power control and game theory for routing, and energy optimization using dynamic systems.
Keywords: *Dynamic Power Control, Energy Harvesting, Game theory routing, Wireless Sensor Networks (WSNs).*

1. Introduction
Wireless sensor networks are made of spatially distributed sensor nodes that observe and monitoring the physical or environmental conditions. Energy efficiency is a critical matter in WSNs due to the limited battery capacity of sensor nodes and the difficulty of replacing or recharging them is one of the challenging aspects in IoT systems. This paper mainly addresses the challenge of energy efficiency by investigating several key strategies: energy harvesting mechanism, communication over power consumption, dynamic power control, game theory-based routing, and overall energy optimization using these techniques.

1.1.Energy Harvesting Model
Energy harvesting is the process which captures energy from external sources and converts it into usable electrical energy. One of the Common energy sources vibration (piezoelectric and triboelectric), and electromagnetic radiation matters in the harvesting of energy that mentioned in the paper.[5]

1.2. Piezoelectric Energy Harvesting
The power produced by a piezoelectric harvesting is modeled as the sine wave of the following pattern: Ppiezo=ηpiezo*0.1*sin (Einput) Where Ppiezo consider as the output power, ηpiezo is the efficiency of the piezoelectric harvesting system, and Einput is the input energy giving to the system. [1] – [4] Calculation Example: Assume ηpiezo= 0.2 and Einput= π/2. Then, Ppiezo= 0.2 * 0.1 * sin (π/2) = 0.02. The Figure 1 below shows the respective output in the harvesting mechanism.

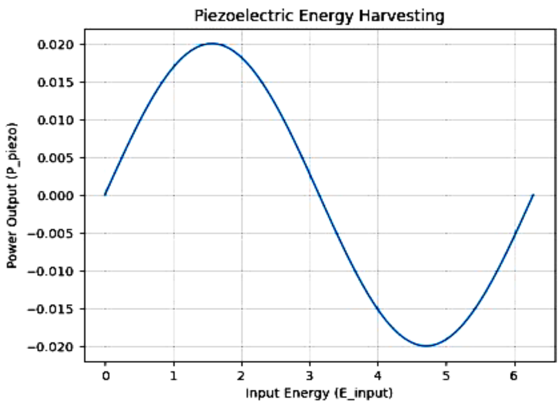

Figure 1 Piezoelectric Harvesting

1.3. Triboelectric Energy Harvesting
The power generated by a triboelectric harvester is modeled as: Ptribo=ηtribo*0.2*log (Einput+1) Where Ptribo is the power output, ηtribo is the efficiency of the triboelectric harvester, and Einput is the input energy.[10] Calculation Example: Assume ηtribo=0.3andEinput= 9. Then, Ptribo = 0.3 * 0.2 * log(9 + 1) = 0.06 (assuming base-10 logarithm). The below figure depicts the analysis of the Tribolelectric mechanism in energy harvesting.

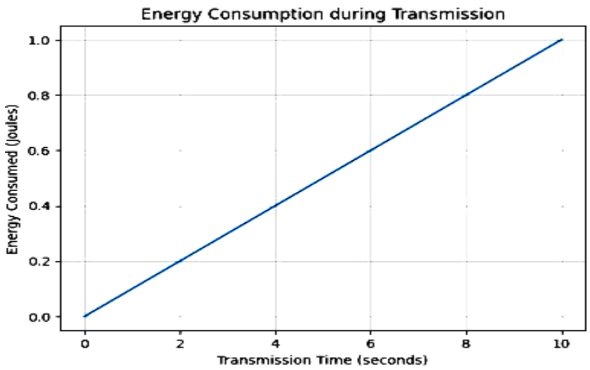

Figure 2 Triboelectric Harvesting

1.4. Electromagnetic Energy Harvesting

The power produced by an electromagnetic harvester is modeled as: Pem=ηem·0.05·Einput Where Pem is the power output, ηem is the efficiency of the electromagnetic harvester, and Einput is the input energy. [12] Calculation Example: Assume ηem=0.4 and Einput=100. Then, Pem=0.4*0.05*√100=0.2. Figure 2 shows Triboelectric Harvesting.Figure 3 shows Electromagnetic Harvesting.

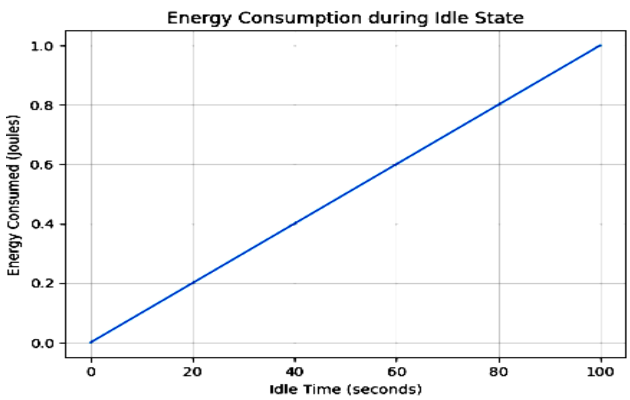

Figure 3 Electromagnetic Harvesting

2. Method

2.1. Communication Power Consumption Model

The energy consumed during communication is a major factor in the overall energy consumption by WSNs. The power consumption varies depending upon the state of the communication module containing three states (transmission, idle, or sleep). [19]-[20]

2.2. Power Consumption during Transmission

Ptransmit=Ttime·Ptx. Where Ptransmit consider as the power consumed during transmission, Ttime should be the transmission time, and Ptx consider as the transmission power.

2.3. Power Consumption during Idle State

Pidle=Tidle·Pidle_state. Where Pidle is the power consumed during the idle state, Tidle is the idle time, and Pidle_state is the power consumption in the idle state. Calculation Example: Assume Tidle = 10 seconds and Pidle_state = 0.01 Watts. Then, Pidle= 10 * 0.01 = 0.1 Joules.Figure 4 shows Energy Consumption In Transmission.

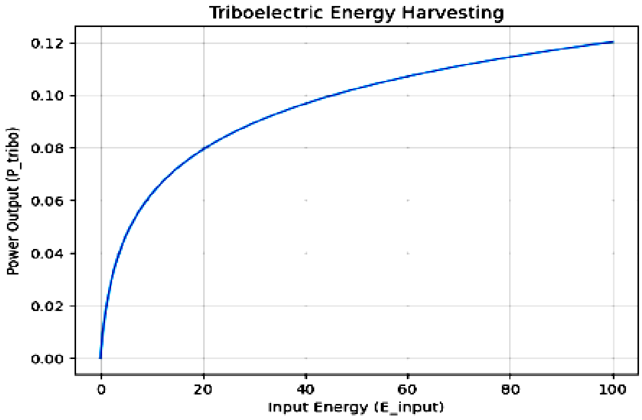

Figure 4 Energy Consumption in Transmission

2.4. Dynamic Power Control

Dynamic power control is a technique used to adjust the transmission power of sensor nodes based on the total available energy. This helps to conserve the energy when it is required and utilize more power when it is abundant. The nodal process made easy control of the sensor nodes present and feasible to analyse. The power control strategy is defined as: If Eavailable>0.8, then Ptx=Pmax If 0.3<Eavailable≤0.8, then Ptx=0.5. Pmax. If Eavailable ≤ 0.3, then Ptx = Pmin Where Eavailable is the available energy, Ptx is the transmission power, Pmax is the maximum transmission. Power and Pmin is the minimum transmission power. Calculation Example: Assume Pmax= 0.2 Watts and Pmin= 0.05 Watts. If Eavailable=0.9, then Ptx=0. 2Watts.If Eavailable=0.5, then Ptx = 0.5*0.2= 0.1 Watts If Eavailable = 0.2, then Ptx = 0.05 Watts

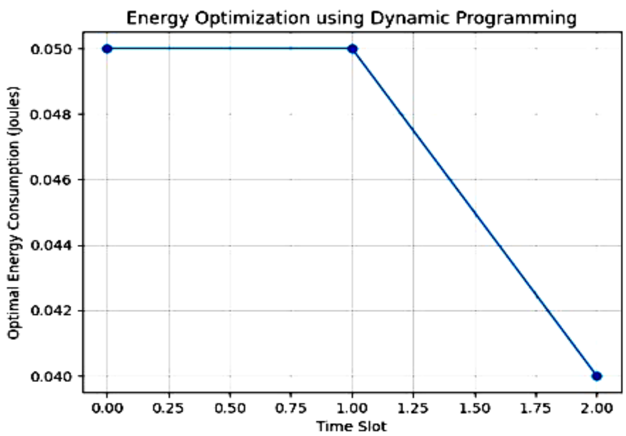

Figure 6 Energy Optimization

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2.5.Game Theory for Routing

Game theory can be used to model routing decisions in WSNs, where each node acts as a player trying to optimize its energy consumption while ensuring efficient data delivery. The routing strategy based on game theory is defined as: If Enode > 0.7, the node chooses a high-power route. If 0.4 < Enode ≤ 0.7, the node chooses a medium-power route. If Enode ≤ 0.4, the node chooses a low-power route Where Enode is the energy level of the node present. Calculation Example: If Enode=0.8, the node selects a high-power route. If Enode=0.5, the node selects a medium-power route. If Enode = 0.3, the node selects a low-power route.

2.6. Energy Optimization

Dynamic programming can be employed to optimize the energy usage in WSNs by determining the optimal communication schedule based on energy harvesting and consumption patterns. This analysis done using the grace value giving for energy. The dynamic programming approach is defined as: Let n be the number of time slots. Let dp be an array of size n where dp[i] represents the optimal energy consumption up to time slot I dp [0] = Pcomm [0] if Eharvest [0] ≥ Ethreshold, else dp [0] = 0 Forifrom1ton-1: If Eharvest [i] ≥ Ethreshold: dp [i] = max (dp[i-1]-Pcomm [i],Pcomm [i]) Else: dp[i]=dp[i-1] The optimal energy consumption is dp[n-1]. Where Eharvest[i] is the harvested energy at time interval i, Pcomm[i] is the communication power at time interval i, and Ethreshold is the minimum energy threshold for communication. Table 01 shows Energy Harvesting Type.

Table 1 **Energy Harvesting Type**

Energy Harvesting Type	Description
Piezoelectric Harvesting	Models power from vibration/pressure, where output depends on efficiency and input energy sinusoidally.
Triboelectric Harvesting	Models power from contact electrification, output related to efficiency and logarithm of input energy.
Electromagnetic Harvesting	Models power from electromagnetic induction, output depends on efficiency and square root of input energy.

Calculation Example: Let's consider 3timeslots (n=3).Assume Ethreshold= 0.1Joules and the following values: Eharvest [0] = 0.2 Joules, Pcomm [0] = 0.05 Joules Eharvest[1]=0.05Joules,Pcomm [1] = 0.06 JouleEharvest [2] = 0.15Joules,Pcomm [2]=0.04Joules Calculations: dp [0] = 0.05 (since Eharvest[0] ≥ Ethreshold) For i = 1: Eharvest [1] < Ethreshold, so dp[1] = dp[0] =0.05. Fori=2: Eharvest [2] ≥ Ethreshold, so dp [2] = max (dp [1] – Pcomm [2], Pcomm [2]) = max (0.05 - 0.04, 0.04) = 0.04. The optimal energy consumption up to time slot 2 is 0.04 Joules. Figure 6 shows Energy Optimization.

3. Results and Discussion

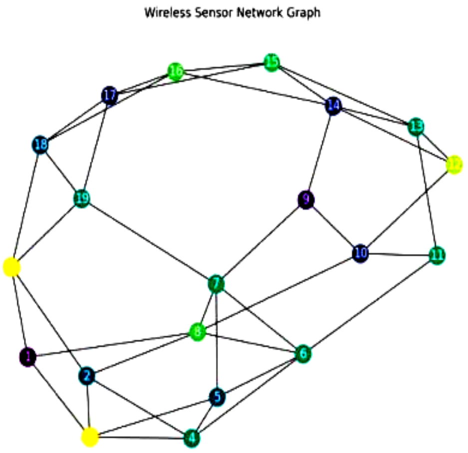

Figure 7 **Wireless Sensor Network**

Figure 7 shows wireless sensor network. The results demonstrate and proclaimed the effectiveness of the proposed energy-aware communication strategies. The piezoelectric energy harvesting model shows the power output over time. The communication model illustrates the difference in power consumption between transmission and idle states. The dynamic power control model show transmission power is adjusted based on available energy levels. The game theory model provides routing decisions based on energy levels. Finally, the energy optimization model calculates the optimal energy consumption using dynamic programming. Table 2 shows power consumption based on states.

3.1. Observation Tables

Table 2 **Power Consumption based on states**

Power Consumption State	Description
Transmission State	Calculates energy used during data transmission as a product of transmission power and time.
Idle State	Calculates energy consumed during inactive periods, based on idle power and duration.

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Conclusion

This paper presents a detailed frame work for energy-aware communication strategies in WSNs especially for IoT networks. The models present in this paper for energy harvesting, communication over power consumption, dynamic power control concept, game theory routing the special algorithm used here and energy optimization and improved mechanism details are provide a comprehensive analysis approach to maximizing network lifetime. The results got here highlight the importance of adaptive energy management techniques for WSNs. Future work may be involving and implementing the validating the models describe here in real-world sensor network deployments and exploring more complex energy harvesting scenarios and routing algorithms. Make the network complexity easy in the sense of power consumption.

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