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OPTIMAL TRUST BASED ENERGY EFFICIENT PROTOCOL FOR WSN

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Abstract

The, Wireless Sensor Networks (WSNs) have undergone revolutionary development within the realm of communication networks. These networks, comprised of interconnected sensor nodes, collaborate to collect information from their surroundings. Despite the widespread popularity of WSNs, they present various challenges, including transmission issues, reception problems, idle listening, and overhearing problems for traditional sensor nodes. In response to these challenges, numerous researchers have introduced different frameworks to address the limitations of WSNs. A previous system proposed the integration of a Wake-up Radio (WuR) system to mitigate the conventional problems associated with WSNs. While the WuR system demonstrated improved performance, it fell short of industry expectations due to factors such as false wake-up interference, sensitivity range, and frequency allocation, which resulted in increased power consumption and overhead in WSNs. To overcome the limitations of the WuR system, this research introduces a novel framework for WSNs, termed the Optimal Trust-Based Frequency Allocation (OTBFA) framework. The proposed OTBFA operates with low power consumption, mitigates network overhead in WSNs, and optimally allocates resources within the network. The implemented system, using network simulation version 2, exhibits superior performance compared to traditional and previous system networks.

Keywords: *Wireless Sensor Networks, Wake up Radio system, False Wake up Interference, Frequency Allocation*

1. Introduction

Wireless Sensor Networks (WSNs) play a crucial role in data transmission, with sensor nodes operating on battery power, determining the network's lifespan. However, these nodes face challenges, constrained by limited power and high energy consumption during network operations. A significant open challenge in WSNs is the reduction of energy consumption for data transmission, prompting researchers to focus on achieving energy-efficient networks without requiring user intervention.

Two primary issues contribute to energy wastage in radio communication networks: idle listening and overheating problems. Idle listening occurs when a sensor node is in an active state, but no data transmission is taking place, while overheating results from a sensor node receiving data without traffic being intended for that node. The implementation of duty cycle mechanisms in WSNs aims to address idle listening and overhearing. Conventional duty cycle mechanisms involve sending sensor nodes to sleep mode periodically and waking them up regularly to assess the potential receipt of packets. Despite the effectiveness of duty cycle mechanisms, they fall short in reducing idle listening, leading to energy wastage and delays in the network.

To address these challenges, the Wake-up Radio (WuR) system is introduced in WSNs, operating at low power consumption and reducing latency in data transmission. The WuR system comprises Wake-up Transmitter (WuTx) and Wake-up Receiver (WuRx) attached to sensor nodes. The WuTx sends a Radio Frequency (RF), also known as the Wake-up Call (WuC), to the intended node connected to WuRx. The node's Micro Control Unit refrains from transmitting data until it receives the WuC.

The remaining of the paper is structures as follows. In section II provides review of literature on different MAC protocols and WuR systems for WSNs. Section III provides a problem statement and the proposed methodology. Section IV presents network environment and simulation results while section VI concludes the proposed framework.

2. Related Work

This section delves into literature pertinent to the Wake-up Radio (WuR) system in Wireless Sensor Networks (WSNs) with a focus on reliable data transmission. The discussion encompasses various WuR frameworks and provides insights into specific researchers' work, highlighting advantages, limitations, and applications.

Peng M et al [2] introduced the RS-CPR scheme, which combines relay node selection with consecutive packet routing, significantly enhancing network performance. Theoretical analysis and experimental results demonstrate that the RS-CPR scheme reduces end-to-end delay compared to the Receiver-Initiated Consecutive Packet Transmission WuR (RI-CPT-WuR) scheme and RI protocol. Der-Jiunn Deng et al [3] presented a comprehensive understanding of the PHY/MAC operations of IEEE 802.11ba WuR, covering wake-up operations, WuR beacon transmissions, WuR mode, re-discovery, channel access in the MAC layer, and waveform, modulation, and preamble designs in the PHY layer. Simulation results indicate superior performance in synchronization error rate and Packet Error Rate (PER) compared to random sequence and M-sequence approaches.

Florin et al. proposed a radio-frequency system promoting energy efficiency in sensor nodes. While achieving energy consumption outperformance, the system faces limitations related to false wake-ups in WSNs [11].

Joaquim Oller et al [12] introduced the Sub Carrier Modulation Wake-up Radio system for energy efficiency in WSNs, demonstrating high efficiency for single and multi-hop scenarios. However, its applicability is limited to inbound frequency channels and specific topologies. Yan et al [14] proposed an ultra-low-power wake-up radio system to minimize signaling overhead and create low-power consuming applications. While enhancing sensor node connectivity and energy efficiency, the multi-hop relaying schema is efficient primarily for indoor applications. Richard et al [16] discussed Wake-up Receiver (WuRx) and preamble sampling MAC protocols in WSNs. WuRx prioritizes connectivity with more deployed nodes but consumes more power compared to preamble sampling in MAC protocols.

Raja et al [19] proposed an adaptive radio system for WSNs, optimizing power usage based on network traffic conditions. Although achieving energy efficiency, the system lacks interdependencies between nodes and compatibility with various protocols such as MAC, routing, and scheduling. J. Polastre et al [20] proposed the Byte-level Medium Access Control (B-MAC) protocol for WSNs. B-MAC emits preamble information to wake up nodes, overcoming latency issues and reducing duty cycle ratio for improved efficiency.

M. Buettner et al [21] introduced X-MAC-UPMA as the base MAC protocol for the Contiki operating system in WSNs. The protocol involves the transmitter alternately sending short preamble packets and listening to the channel, with intended nodes responding immediately with an acknowledgment frame upon reception.

3. Methodology

3.1 Problem Statement

Wireless Sensor Network (WSN) applications heavily rely on battery power to ensure prolonged operation without human intervention. Particularly in critical applications, sensors play a vital role, being essential for deployment in harsh and inaccessible environments. However, conventional networks exhibit high energy consumption during data transmission, leading to a significantly limited lifespan for sensors. In response to the challenges posed by traditional networks, an energy-efficient Wake-up Radio (WuR) system was introduced in WSNs. While the WuR system succeeded in establishing low-power, energy-efficient networks, it faced issues such as false wake-up interference, sensitivity range limitations, and challenges in frequency allocation within WSNs. To overcome these hurdles, this research proposes a novel framework known as the Optimal Trust-Based Frequency Allocation (OTBFA) framework.

3.2 Trust Path for WuS

Within the proposed Optimal Trust-Based Frequency Allocation (OTBFA) framework, the calculation of trust paths is integral for transmitting Wake-up Signals (WuS). At the outset, each node or link possesses a foundational trust factor value. In the Wireless Sensor Network (WSN), numerous paths exist from the source to the destination.

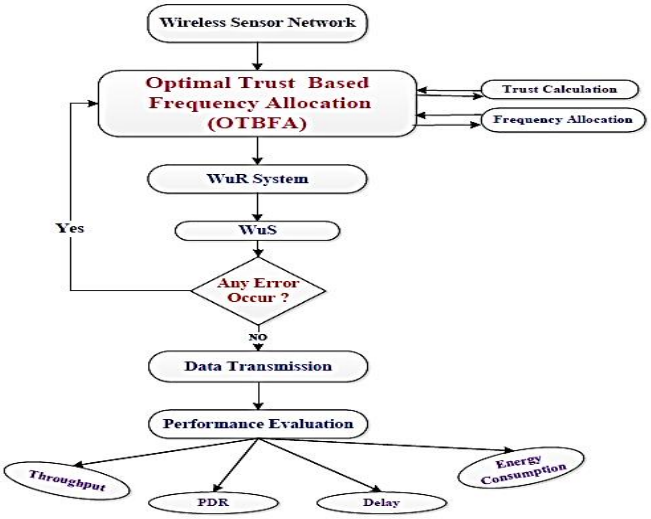

Fig 1- Proposed OTBFA Architecture

The depicted architecture is illustrated in Figure 1. The trust factor for each path is computed by aggregating the link trust factor values. Numerous intermediate nodes are engaged in forming a path from the source to the destination. Within the network, each node maintains the trust values of its neighboring nodes. Upon reaching the receiver node, the trust value for all paths is calculated. The sender node then transmits the Wake-up Signals (WuS) to the destination node through the path with the highest trust value. The second-highest trust value paths are retained as backup paths, to be utilized in case of network failures. Algorithm 1 outlines the proposed trust path calculation algorithm based on trust values.

```
Algorithm 1: Trust Factor Calculation
Input: Sensor nodes with trust factors
Output: Trust paths with highest trust values
        1. Start
        2. Source node initiate calculate trust factor value
        3. First intermediate node adding trust factor value
        4. Second intermediate node again adds trust factor value
        5. At destination node calculate total trust value of path
        6. Trust value of path = TFVs +TFVn1 + TFVn2 + ------- +TFVnn + TFVd
        7. Arrange the trust value paths in descending order
        8. Select highest trust value path
        9. Then source node start sends WuS.
        10.         If any error occurs
        11.         Select second highest trust value path
        12.         Start send WuS through secondary path.
End
```

3.3 Optimal Frequency Allocation

The Optimal Layer Frequency Allocation proves to be a superior solution for Wireless Sensor Networks (WSN). This schema operates efficiently in conjunction with the Wake-up Radio (WuR) system, effectively addressing physical layer challenges such as sensitivity issues and bandwidth allocations. Given that WSN networks experience both high and low traffic, the implementation of Optimal Frequency Allocation becomes crucial for optimizing resource utilization. This approach ensures the optimization of network sensitivity and frequency, aiming to circumvent network overhead and achieve low power consumption in WSN.

4. Results and Analysis

The implementation of the proposed Optimal Trust-Based Frequency Allocation (OTBFA) framework to address limitations and enhance the performance of the Wake-up Radio (WuR) system in Wireless Sensor Networks (WSN) is carried out using Network Simulator (NS) version 2.35. Through the application of OTBFA, the performance of the WuR system in terms of data transmission is thoroughly analyzed, and the simulation results are presented in the subsequent subsections. Table 1 shows the network environment for performance analysis

Table 1: Network Simulation Environment

S NO	Parameter Type	Parameter Value
1	Channel Type	WirelessChannel
2	Radio-Propagation	Propagation/TwoRayGround
3	Network Interface Model	WirelessPhy
4	Interface Queue Type	DropTail
5	Antenna Model	OmniAntenna
6	Interface Queue Length	50
7	Routing Protocol Type	AODV
8	No.of Nodes	100
9	Simulation Time	50 Sec

As depicted in Table 1, the wireless sensor network parameters have been configured for the network simulation, utilizing Two Ray Ground radio propagation. The proposed framework is assessed through various performance metrics, which are detailed in the subsequent subsection. The efficiency of the proposed mechanism in enhancing network quality of service is evaluated using performance metrics such as energy consumption, latency, packet delivery ratio, and average power consumption, all of which are briefly described in the following subsections.

4.1 Delay Performance Comparison

Table 2. Delay Performance Comparison Results

No.of Nodes	RI_WuR	RS_CPR_WuR	OTBFA-WuR
10	22500	9500	2200
20	48000	21500	4500
30	66000	35300	6400
40	70000	38400	7200
50	72000	39800	8400

Illustrated in Table 2, a notable enhancement in performance is evident when comparing the previous systems with the proposed system, particularly in terms of average delay. The X-axis reflects values such as 10, 20, 30, 40, and 50. The proposed system demonstrates lower delays across these values. Notably, at 50 nodes, the network delay increases, following a similar trend observed in previous systems. Nonetheless, the average delay of the proposed system is considerably lower than that of the previous systems.

Figure 2 further illustrates this comparison, where the horizontal axis represents the number of nodes, and the vertical axis represents the exhibited average delay performance. The proposed system exhibits significant performance improvement, aligning with a similar trend observed in the existing system [2][5]. However, the performance of the proposed system stands out as significantly superior across all recorded node values.

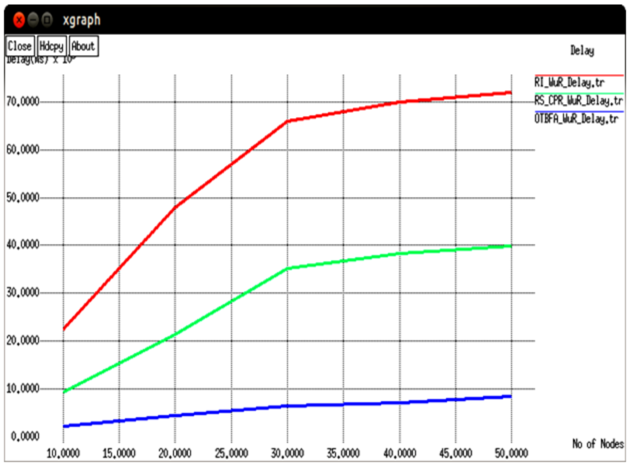

Fig 2. Performance on Delay

4. 2. Throughput Performance Comparison

As indicated in Table 3, a notable enhancement in performance is observable when comparing the previous system with the proposed system, particularly in terms of throughput. The X-axis is marked with values such as 10, 20, 30, 40, and 50 representing the number of nodes. The proposed system exhibits commendable throughput performance across these node values. Particularly, at a simulation time of 50, the network demonstrates high throughput, a trend similarly observed in previous systems. Nevertheless, the throughput of the proposed system significantly surpasses that of the previous system.

Table 3. Throughput

No. of Nodes	RI_WuR	RS_CPR_WuR	OTBFA-WuR
10	12	50	75
20	30	140	240
30	50	230	360
40	72	310	420
50	100	390	680

Illustrated in Figure 3, the horizontal axis denotes the number of nodes, and the vertical axis reflects the exhibited throughput performance. The proposed system demonstrates a notable improvement in performance.

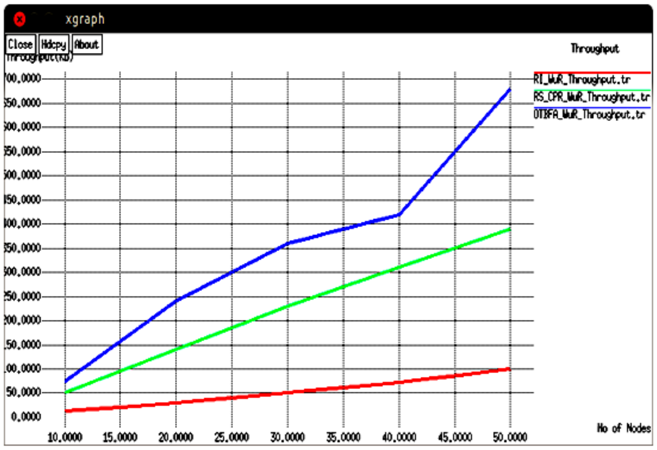

Fig 3 Performance on Throughput

Similar trend is with the existing system [2][5]. However, the performance of the proposed system from starting to end simulation recorded is significantly better.

4.3 Energy Performance Comparison

Table 4 Energy Comparison Results

No. of Nodes	RI_WuR	RS_CPR_WuR	OTBFA-WuR
10	22000	5000	2200
20	42500	7200	3600
30	50200	10100	4800
40	90100	21000	8350
50	110000	32000	10200

As depicted in Table 4, a noticeable enhancement in performance is apparent when comparing the existing systems with the proposed system, specifically in terms of energy consumption. The X-axis is marked with values such as 10, 20, 30, 40, and 50, representing the number of nodes. The proposed system exhibits commendable energy performance across these node values. Particularly, at 50 nodes, the network demonstrates high energy consumption, a trend similarly observed in previous systems. However, the energy efficiency of the proposed system outperforms, showing significantly lower values in comparison to RI_WuR and RS_CPR_WuR.

Additionally, Figure 4 illustrates this comparison, where the horizontal axis represents the number of nodes, and the vertical axis represents the exhibited Packet Delivery Ratio (PDR) performance. The proposed system demonstrates a noteworthy improvement in performance [2][5].

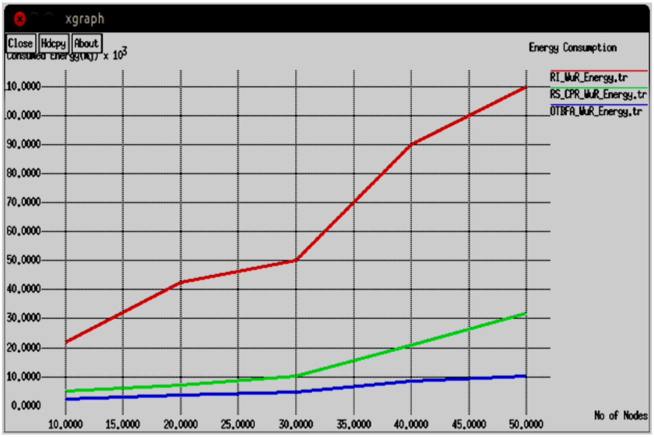

Fig 4. Performance on Energy

Similar trend is with the existing system. However, the performance of the proposed system at all duty cycles recorded is significantly better.

4.1.4 Packet Sent

Table 5. Packet Sent Results

No.of Nodes	RI_WuR	RS_CPR_WuR	OTBFA-WuR
50	1000	1165	2240
100	830	1140	2115
150	760	1030	2055

Illustrated in Table 5, the table provides information on the packets sent by both existing and proposed systems. Notably, the proposed system exhibits substantial performance improvement compared to the previous systems. The number of nodes ranges from 50 to 150 nodes [2]. The proposed framework demonstrates superior performance when compared to previous Wake-up Radio (WuR) systems.

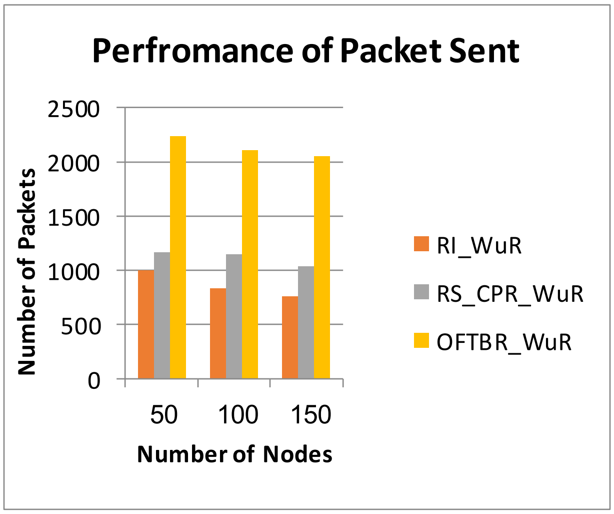

Fig 5. Performance on Network Life Time

As depicted in Figure 5, the horizontal axis denotes the number of nodes, and the vertical axis illustrates the results for network packets sent. The results reveal two significant observations. Firstly, the Optimal Trust-Based Frequency Allocation (OTBFA) approach exhibits superior performance when compared to other Wake-up Radio (WuR) approaches [2][5]. Secondly, there is an increase in the number of packets sent for the proposed approaches as the number of nodes increases.

5. Conclusion

In this research work, we delved into various facets of the Wake-up Radio (WuR) system within Wireless Sensor Networks (WSN), including issues like false wake-up interference, network sensitivity range, and frequency allocation. To counter false interference, our proposed Optimal Trust-Based Frequency Allocation (OTBFA) framework employs a trusted path for the transmission of Wake-up Signals (WuS). Given WSN's association with different layers of the network model, our OTBFA framework concentrates on optimizing the physical and MAC layers. In the physical layer, we optimize network sensitivity and employ optimized frequency allocation to enhance data transmission. Simultaneously, the MAC layer is optimized to minimize the overall power consumption of the network. Our experimental results highlight the significant improvement in performance achieved by the proposed framework compared to previous WuR systems.

References

1. Lopez-Aguilera, E. and Garcia-Villegas, E., 2021. Bandwidth-Based Wake-Up Radio Solution through IEEE 802.11 Technology. Sensors, 21(22), p.7597.
2. Peng, M., Liu, W., Wang, T. and Zeng, Z., 2020. Relay selection joint consecutive packet routing scheme to improve performance for wake-up radio-enabled WSNs. Wireless Communications and Mobile Computing, 2020.
3. Deng, D.J., Lien, S.Y., Lin, C.C., Gan, M. and Chen, H.C., 2020. IEEE 802.11 ba wake-up radio: Performance evaluation and practical designs. IEEE Access, 8, pp.141547-141557.
4. Trotta, A., Di Felice, M., Bononi, L., Perilli, L., Scarselli, E.F. and Cinotti, T.S., 2020, June. Throughput Enhancement in UAV-aided Wireless Sensor Networks via Wake-Up Radio Technology and Priority-based MAC Scheme. In 2020 IEEE 6th World Forum on Internet of Things (WF-IoT) (pp. 1-6). IEEE.
5. Guntupalli, L., Ghose, D., Li, F.Y. and Gidlund, M., 2018. Energy efficient consecutive packet transmissions in receiver-initiated wake-up radio enabled wsns. IEEE Sensors Journal, 18(11), pp.4733-4745.

6. Mathew L. et al. (2017). BladeMAC: Radio Duty-Cycling in a Dynamic, Cyclical Channel. IEEE ICC. 1 (1), p1-7.
7. Rajeev Piyare et al. (2017). Ultra Low Power Wake-Up Radios: A Hardware and Networking Survey. https://www.researchgate.net/publication/318378481. 1 (1), p1-14.
8. Nour Mohammad Murad et al. (2016). An Energy-Efficient Duty-Cycled Wake-Up Radio Protocol for Avoiding Overhearing in Wireless Sensor Networks. Scientific Research Publishing Inc. 14 (8), p176-190.
9. Fatima Zahra Djiroun et al.. (2016). MAC Protocols with Wake-up Radio for Wireless Sensor Networks: A Review. IEEE. 1 (1), p1-35.
10. Joaquim Oller et al. (2015). Has Time Come to Switch From Duty-Cycled MAC Protocols to Wake-Up Radio for Wireless Sensor Networks?. IEEE/ACM TRANSACTIONS ON NETWORKING. 1 (1), p1-14.
11. HUTU Florin et al. (2014). A new wake-up radio architecture for wireless sensor networks. https://www.researchgate.net/publication/269520075. 1 (8), p1-14
12. Joaquim Oller et al. (2014). Performance Evaluation and Comparative Analysis of SubCarrier Modulation Wake-up Radio Systems for Energy-Efficient Wireless Sensor Networks. sensors. 14 (1), p22-51.
13. Dr.S.Rajaram et al. (2014). SECURE ROUTING PATH USING TRUST VALUES FOR WIRELESS SENSOR NETWORKS. International Journal on Cryptography and Information Security (IJCIS). 4 (2), p27-36.
14. Yan Zhang et al. (2012). Wake-up Radio Assisted Energy-aware Multihop Relaying for Low Power Communications. IEEE. 1 (1), p2498-2503.
15. N.Karthik et al. (2011). TRUST CALCULATION IN WIRELESS SENSOR NETWORKS. International Conference on Electronics Computer Technology. 4 (1), p376-380.
16. Richard Su et al. (2010). Comparison between Preamble Sampling and Wake-Up Receivers in Wireless Sensor Networks. IEEE Communications Society. 1 (1), p1-5.
17. Raja Jurdak et al. (2010). Radio Sleep Mode Optimization in Wireless Sensor Networks. IEEE TRANSACTIONS ON MOBILE COMPUTING. 9 (7), p955-968.
18. Dr.S.Rajaram et al. (2014). Secure Routing Path Using Trust Values For Wireless Sensor Networks. International Journal on Cryptography and Information Security (IJCIS). 4 (2), p27-36.
19. Raja Jurdak et al. (2008). Adaptive Radio Modes in Sensor Networks: How Deep to Sleep?. IEEE. 1 (1), p386-394.
20. M. Buettner, G. V. Yee, E. Anderson, and R. Han, “X-MAC: A short preamble MAC protocol for duty-cycled wireless sensor networks,” in Proc. 4th Int. Conf. Embedded Netw. Sensor Syst., 2006, pp. 307–320.
21. J. Polastre, J. Hill, and D. Culler, “Versatile low power media access for wireless sensor networks,” in Proc. 2nd Int. Conf. Embedded Networks. Sensor Syst., 2004, pp. 95–107