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Research

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Abstract

Wireless Sensor Network (WSN) is one of the emerging key technologies in 21st Century. WSN are deployed in large environment, hence the sensor node performance are prone to the effect of internal energy and external temperature. If the environmental temperature increases, it automatically influences the node's temperature, worsens lifetime of the network and Quality of Service (QoS) parameters. To eliminate this issue, Environmental Aware Thermal (EAT) routing protocol was proposed. It consists of three potential fields such as environment, QoS and energy and two threshold levels. The routing path decisions are made based on surrounding environmental temperature. A routing path where the nodes with high energy are selected. The incoming data packets are assigned with three priority levels (critical, abnormal and normal). An optimum path is selected in which the node satisfies the criteria for threshold levels and environmental temperature. The selected path ensures that the critical data packets reaches destination on time with minimum delay. The simulation was carried out for three different cases (1, 2 & 3) and from the experimental results it is inferred that proposed protocol shows improvement in delay and network lifetime of WSN.

Keywords: Wireless Sensor Network, Environmental Temperature, Quality of Service, Multipath routing protocol, Environmental Aware Thermal Routing Protocol

1. Introduction

The recent development in sensor technology and wireless communication devices has attracted the engineering researchers towards Wireless Sensor Networks (WSN). A WSN comprises of a group of autonomous sensors which are spatially distributed in an environment to sense and transmit the physical signals by collaborating with one another. The collected signals are again transmitted to sink/base station for further processing. A WSN are widely used in military surveillance, environmental monitoring, process automation, health care, precision

agriculture and industrial control [1]. Recently the role of WSN in medical applications is increasing thus leading to evolution of Wireless Body Area Sensor Networks (WBASN). A WBASN is a category of WSN which specifically deals with healthcare applications. It consists of tiny group of biomedical sensor nodes to diagnose and monitor the health condition of human beings. These sensors prevent the people from life threatening diseases at the early stage. A WBASN is responsible to provide real time, improved and cost effective solution to improve quality of life. [2]. The tiny sensors in WBSNs are deployed randomly or in a planned manner with certain topology. In general, the information sensed from surroundings is forwarded to the sink either through single-hop connectivity or multi-hop connectivity. At present, to main the quality of data transmission multi-path routing protocols are highly preferred [3]. Additionally, the node links are prone to attacks, faults and misbehaviors due to adverse environmental conditions such as rainfall, fog, humidity, particulate matter (CO₂) and high temperature [4].

Nowadays, the studies considered the occurrence of path loss due to changes in environmental factors. It is easily affected by several factors such as frequency of signal, distance between source and destination and propagation medium (moist or dry air) [5]. The temperature variation produces difference in clock frequencies of sensor nodes. Basically, general assumptions are made that the temperature of sensor nodes remains constant for a specific time interval. Thus temperature compensation algorithm is utilized during clock error estimation to determine the environmental temperature with the help of sensor network platforms [6]. From the recent studies, the temperature remains still an unpredicted factor. The performance of battery, aging of electronic components, efficiency of components and efficiency of transceivers are easily affected by the temperature [7]. Bannister et al. [8] calculated the influence of temperature on radio transceivers. It was observed that there is a degradation in Received Signal Strength Indicators (RSSIs) and packet reception rate (PRR) in deployed WSN at higher temperature. Boano et al. [9] identified the variations at 56°C. Hence the transmission power is raised to diminish the effect on transmission unit [10]. In [11] the authors analysed that nodes operating at high temperature for long duration causes the microcontroller unit to slow down the voltage production thereby minimizes the speed of node operation. However, in order to optimize the battery's discharge characteristics it is necessary to gather information about the surrounding environment temperature and its influence on sensor node [12]. The

exposure of sensor nodes to high temperature (25°C to 65°C) degrades the received signal strength and link quality gradually [13]. However, operating at lower temperatures might require up to 16% less power to maintain a reliable communication [1]. Another issues faced is that the devices gets heated normally operating at high temperature which is being absorbed by the human tissue and increases body temperature. Hence to save battery's life and to limit temperature rise, energy should be conserved within the sensor network. The total amount of heat being absorbed by human body in general is termed as specific absorption rate (SAR) [14].

Routing in WSN is challenging and it varies from wired and wireless networks [15]. Thus routing path should be estimated carefully else it leads to increased error rates [16]. the lifetime of sensor nodes depends on battery lifetime [17]. Each node in multipath routing protocol act both as sender and receiver, in case of any faults in one of the nodes causes reorganization and rerouting of packets in networks. The routing protocol depending on QoS parameters should balance the energy consumption and data quality. Sequential Assignment Routing [18] routing protocol considers QoS metrics. It mainly relies on QoS on each path, energy resources and priority level. is one of the first routing protocols for WSNs to introduce the notion of QoS into routing decisions. Chang, J.H. and Tassiulas, L [19] estimated routing path through the nodes with maximum energy and it switches to an alternative path if it identifies nodes with increased energy. Dulman, S et al. [20] routing path is established between nodes to transmit the data even in unreliable environment. Srivastava A et al. [21] the algorithms are based on localization. Several drawbacks such as inaccurate positioning, broadcast overheads, optimum problem in forward selections are encountered. Qureshi, K.N et al. [22] Energy Aware Routing (EAR) protocol are presented. In this algorithm the routes are established by determining the energy level to balance the load under heavy traffic, link quality for successful data transmission. Gouda, K.C et al. [23] protocols are designed by taking time management, threshold level and priority level of packets into consideration. Ahmed, O et al. [24] EOCC-TARA (Energy Optimized Congestion Control) based on temperature was designed. the routes are optimized using an EMSMO (Enhanced Multi-Objective Spider Monkey) Optimization on technique. It considers the affect of temperature and establish routing path with congestion avoidance mechanism.

In wildlife monitoring applications, a report on experimental campaigns at three different outdoor environments was characterized by varying degrees of

vegetation. The experiments were carried out in summer, winter, seasonal variations, and span of multiple days at night and daytime. Thelen et al. [25] discussed about the radio propagation through high humidity in potato deployment field. The path loss exponent value was 4 irrespective of different growing seasons. The radio range diminishes to 10 m as the potato crop starts flowering. Thus, it is necessary to deploy sensor nodes at a distance of at most 10 m in precision agriculture application and a micro-climate is sensed during the entire growing season. The influence of the potato foliage is found to be 17 dB, as nodes are placed at a distance of 15 m. G. Anastasi et al. [26] suggested that rain and fog affects the performance of WSN especially in data transmission range and reception. The impact of environmental changes at different weather conditions on energy consumption and the transmission range of WSN are performed. The data transmission range of mica2/mica2dot sensor nodes is poor in presence of rain or fog. Carlo Alberto Boano et al. [27] looked into the variations of link quality and data delivery performance at ambient temperature influence in low-power radio communications. From the obtained experimental results, it is clearly inferred that the communication between sensor nodes gets affected due to temperature and thus minimum transmission power is required at low temperature.

Motivation behind the work

Wireless sensor network plays a vital role in many applications such as health care, precision agriculture, environmental surveillance and military etc. WSN must support certain degree of reliability, energy and delay bound for data transportation to be utilized in these applications. Therefore, it is necessary to design and develop an energy efficient protocol. Apart from these factors, environmental awareness is also an important factor that should be considered in multipath routing protocol design. These are easily influenced by environmental factors like electromagnetic interference, vibration, temperature and humidity. Once the surrounding temperature increases, it degrades the performance of sensor nodes and excessive rise in temperature may burn the sensor nodes. An extreme high humidity environmental condition minimizes the link quality and raises the probability of short-circuitry in sensor nodes. Similarly, a Strong electromagnetic interference increases the data loss rate.

Thus the sensor nodes utilized in healthcare applications must withstand the environmental characteristics and fluctuating channels. Besides, a communication protocol must be designed to maintain a bounded packet delivery rate (during critical

stage of human) though there is drop in established link. The sensor nodes deployed at the outdoor environment usually experiences high fluctuation due to the variation in weather conditions. Thus designed protocol must withstand variations in environmental condition, channel fluctuations and successful data delivery. If the designed routing protocol fails to adhere to the environmental changes and the data packets routed through a sensor nodes are affected by temperature once it crosses a heat zone, data delivery through this particular path is terminated. In case of environment-aware routing, if the routing path senses extreme temperature it adjusts to an alternate routing path to prevent data loss.

Novelty of this work

Many researchers tried to incorporate the impact of environmental influence into the network's performance. But none of them could find an appropriate and reliable result for the influences of different environmental conditions. However, the main parameter degrading the network life time and quality of service is very scanty in literature and only very few environmental parameters like fog, moisture, humidity, and reflecting angle was considered.

Hence, this paper aims to develop an invulnerable routing protocol which resist against an environmental impact. Thus an Environmental Aware optimum path optimum temperature (EAOPOT) Protocol is developed. It based on three independent virtual potential fields such as energy, environment and quality of service. The energy field ensures that the sensor nodes select neighbor nodes with more energy as relay nodes. The environmental field makes sure that the estimated routing path finds an alternative routing path as the sensor node temperature increases beyond the threshold limit. The quality of service field makes the data to reach the destination successfully from the source. The routing path is estimated by satisfying all the above mentioned three virtual potential fields. The major contributions of EAT Protocol are summarized as follows.

1. *Improved routing possibilities under critical temperature zone:* Based on the acquired data from environment, the EAOPOT routing protocols can identify an additional routing path to avoid the critical temperature zone.
2. *QoS field:* To improve the quality of service, the data are assigned with three different priorities (normal, abnormal and critical). This protocol ensures that the critical data will reach the destination node without any delay.

3. *Energy field*: This protocol measures the available remaining energy within the network. If a node want to choose an alternative path due to high temperature zone, then routing path with high energy nodes are selected. Similarly, the relay node with high energy is selected for long distance data transmission.

The rest of this paper is organized as follows: In Section 2, the implementation of proposed EAOPOT Protocol, assumption and flow chart was illustrated. Section 3 discussed about the results obtained from simulation and analyzed the environmental impact on WSN. Finally, the concluded of findings were discussed.

2. Experimentation

To analyse the environmental temperature influence on WSN parameters like lifetime, delay, energy and temperature are estimated using EAOPOT protocol.

2.1 Proposed protocol

The flow chart of proposed EAOPOT routing protocol is shown in figure 1. The complete step by step operation is as follows:

- In initialization phase, source initiates the broadcast to collect information such as temperature, hop distance from source to destination and energy required.
- The neighboring node starts calculating the temperature and remaining energy. If the temperature is less than the threshold value ($Node_temp < Th_min$), the packets are passed to next intermediate node for further processing or else the data packets are discarded. Likewise, the remaining available energy is also calculated. If the node's energy is below the threshold value ($Node_Eng < Th_min$), then the packets are forwarded to the neighboring node
- If both temperature and energy conditions are satisfied, the node calculates the distance between source and destination. A connection is established through a path with minimum hop count. If the distance is too long, then the node will choose a relay node to reach the destination.
- Once the connection is established, the sensor nodes are ready to transmit the packets to destination. Before data transmission, the packets are assigned with different priority levels (critical, abnormal and normal).
- After assigning priority, the protocol checks the surrounding temperature. If it is above the threshold value ($Node_Etemp > Th_max$), then the packets are

retransmitted to source to choose an alternative path. Next, the node's temperature is calculated. If temperature of sensor node is greater than the threshold value ($\text{Node_temp} > Th_max$), the sensor node forwards only critical data signals otherwise all priority signals are transmitted.

Fig.1 Environmental Aware Thermal – Routing (EAT) Protocol

2.2 Sensor node environmental modeling and analysis

The main objective of this paper is to analyze the influence of temperature on sensor node and its effects on the data transmission, delay and energy consumption. However, in atmosphere there are many environmental factors like: Humidity, moisture, electromagnetic interference and temperatures influences on the sensor node's performance. From the above mentioned parameter temperature is one of the most influencing factor which degrades the performance of the sensor node. In this paper, environmental temperature influence on sensor node is focused. Thus, single node environmental influence and multi-node environmental influence is developed to analyze the influence of temperature on sensor nodes.

2.3 Single node environmental influence modeling

The threshold temperature is fixed for each sensor node to identify the surrounding temperature around the single node. The threshold value is fixed based on surrounding temperature for best operation. Each node continuously senses the surrounding temperature. If the surrounding temperature is minimum and below the threshold value (-10°C to 10°C) the values are calculated using Eq.1. If the node is deployed in normal environmental temperature field of 10°C to 80°C, the influence on external environmental influence are set to be 1 as given in Eq.2. At this point, the temperature influence is considered as negligible. If the temperature exceeds maximum threshold value, then Eq.3 is used to calculate the field temperature.

$$T_e^k(n) = N_0^k \quad T^k(n) < T_{low}^k \quad (1)$$

$$T_e^k(n) = 1 \quad T_{low}^k \leq T^k(n) \leq T_{high}^k \quad (2)$$

$$T_e^k(n) = N_1^k \quad T^k(n) \geq T_{high}^k \quad (3)$$

Where $T_e^k(n)$ is a single node surrounding environmental temperature field. T_{low}^k, T_{high}^k are defined as the sensor normal operation at k environmental factor. T_{min}^k, T_{max}^k is the sensor node operating threshold set point. $T^k(n)$ is temperature of individual node at k environmental factor. $N_0^k = \frac{T^k(n) - T_{min}^k}{T_{low}^k - T_{min}^k}$ for low environmental temperature field and $N_1^k = \frac{T_{max}^k - T^k(n)}{T_{max}^k - T_{high}^k}$ is defined for high environmental temperature field. If the data is transmitted through a node (n) and $T^k(n)$ changes at the state 1. It

indicates that the temperature of a particular node increases. At this stage the protocol verifies the T_{max}^k value. If the condition is satisfied, data transmission is terminated through that particular node.

2.4 Multiple node modeling

The data packets are transmitted through multiple nodes to reach its destination. Therefore, multiple node temperature modeling is essential to understand the complete influence of environmental effect on sensor nodes. Due to environmental factor, the lifetime of sensor node, energy of particular node and data losses of the node are being affected. To analyze the environmental temperature $T_m(n)$ influence on sensor node the following Eq.4 is used.

$$T_m(n) = T_{min}\{T_e^k(n1), T_e^k(n2), T_e^k(n3), \dots \dots \dots, T_e^k(n)\} \quad (4)$$

Where $T_m(n)$ is a single node surrounding temperature created by node (n) at k factor. In real time environment, multiple factors like humidity, moisture and electromagnetic interference etc. influences the node performance. In this study only temperature is taken into consideration. The path selection is done based on single node surrounding temperature value. To ensure continuous working of sensor nodes two threshold value: T_{min} and T_{max} are fixed. If the temperature of sensor node increases beyond T_{max} , that specified node area is called as “unsafe zone” and this node is not selected for further communication purpose. This “unsafe zone” data is collected by neighboring node and the same node is continuously monitored until it returns to normal temperature. It is given in Eq.5.

$$T_e(n, p) = k_{(n,p)} T_{min}(n), T_{min}(p) \quad (5)$$

Where $T_e(n, p)$ is the neighboring field temperature potential of node (n) and node (p).

2.5 Sensor node surrounding temperature field

The total environmental temperature of a particular sensor node (n) is defined by combining the multiple node environment $T_m(n)$ and neighboring field environment $T_e(n, p)$. It is given in Eq.6.

$$T_{env}(n) = \frac{T_m(n) + T_e(n,p)}{1 + k_{(n,p)}} \quad (6)$$

Where $T_{env}(n)$ is environment of particular sensor node, $k_{(n,p)}$ environmental factor at node (n) and node (p).

2.6 Sensor node remaining energy calculation

To ensure continuous operation of sensor node, remaining energy calculation is very important. The remaining energy ($E_{ng}(n)$) of particular node is calculated using Eq.7.

$$E_{ng}(n) = \frac{E_r(n,t)}{E_i(n)} \quad (7)$$

Where E_r is the remaining available energy of node (n) at the time of (t), $E_i(n)$ is the initial energy available while deploying the sensor node (n). Utilizing Eq.7 the remaining energy of a particular node at time (t) can be determined. But the required energy for sensor operation is calculated using Eq.8.

$$T_e(n) = \frac{P_t}{T_r} ((n-1) + P_{rx} + nP_{tx} + P_{idl} + P_{slp} + 2P_{Rfrequency_startup}) \quad (8)$$

Where P_{rx} denotes the node receiving operation, P_{tx} performs data transmission, P_{idl} indicates node in idle state, P_{slp} is the nodes in sleep state, $P_{Rfrequency_startup}$ is the radio frequency startup power during transmission, P_t and T_r is the data and transmission rate of packets. In a network, all nodes perform many operations like sensing, transmission, receiving, sleep and idle stage. Each stage of sensor operation consumes different energy level from battery.

2.7 Delay Modeling

When a data packet moves from one node to other node along the desired path to reach destination, it suffers from several types of delay at each node. The delay component at source node includes sensing delay, deals with initialization of nodes for data transmission. Processing Delay, transmission of data packets from one node to another node and queuing delay, associated with delay incurred when all nodes are busy in transmitting the previous data packets. Additionally, transmission and

receiving delay occurs during data transmission and reception at each node. Using Eq.9 the delay estimation is derived as follows:

$$D_n(n) = \left(D_{sn} + D_{prs} + D_{qu} + D_{tx}(n) + D_{rx}(n) \right) + \sum_{jw}^n Rj \quad (9)$$

Where D_n sum of delay, D_{sn} sensing process delay, D_{prs} process delay, D_{qu} queuing delay, D_{tx} transmission delay, D_{rx} receiving delay and $\sum_{jw}^n Rj$ relay node processing delay.

2.8 Simulation parameters

The proposed algorithm is simulated by deploying various nodes randomly in 250×250 m area using MATLAB. The maximum number of nodes allowed is 100 and the transmission range between source to destination is 50m. The ambient environmental temperature is set at 40°C. The minimum operating temperature is 10°C and the maximum operating temperature is 80°C. For simulation model the following assumptions were made: All nodes are in fixed (static) position and all nodes have fixed transmission range. The specific heat of the node is fixed as constant value. The node gets cooled down at the rest state of the sensor node. The multi-hop network model is prepared. During installation, all nodes are placed at uniform distance with equal energy. The simulation parameters used for this analysis is given in Table 1. Figure 2 shows the node deployment and network topology of the network.

Table 1. Simulation Parameter for environmental influence on sensor nodes

Parameters	Values
Total simulation network area	250 × 250 m
Number of sensor nodes	100
Transmission distance between the nodes	50m
Environmental Temperature	40°C
Threshold temperature	10 °C to 80 °C
Specific heat	0.5 j/g
Number of hopes	20
Sensor type	Fixed model
Overheating temperature	-10 °C to 100 °C
Data Transmission rate	250 Kbps
Cooling rate at rest position	2U
Required transmission energy	50 nJ/bit

Fig.2 Node Deployment and Network Topology

Table 2 List of Abbreviations

Notations	Abbreviations
WSN	Wireless Sensor Networks
QoS	Quality of Service
WBASN	Wireless Body Area Sensor Networks
RSSI	Received Signal Strength Indicators
PRR	Packet Reception Rate
SAR	Specific Absorption Rate
EAOPOT	Environmental Aware optimum path optimum temperature
EAR	Energy Aware Routing
EOCC-TARA	Energy Optimized Congestion Control – Temperature Aware Routing Algorithm
EMSMO	Enhanced Multi-Objective Spider Monkey

3. Result and Discussion

In this section, the simulation results for influence of temperature on networks, amount of power consumed by node, sensor network lifetime at three different cases and variation of delay at different temperature was explained in detail.

3.1 Temperature influence on network

The sensor network performance degrades and its malfunction probability also increases sharply at low and high temperature. If the node operates at normal temperature environment then the effect of external surrounding temperature on sensor node performance can be neglected. The figure 3 shows the temperature influence on sensor nodes at three different cases. In case 1, normal operation (no temperature influence) is considered. Here, the sensor node operates at nominal temperature interval and does not consider the influence of temperature on sensor performance. In case 2, the factors influencing the sensor node at different environment field is considered. As the surrounding environmental temperature increases, the sensor node temperature rises linearly at a time interval t . In case 3, the temperature variation of sensor nodes along the routing path due to continuous variation in environmental temperature is analyzed.

Fig.3 Temperature variation of sensor nodes at time of t seconds

3.2 Power Consumption

The average power consumption of a node is found by calculating the difference of available energy at the initial stage and the remaining available energy. The environmental field ensures that the constructed multipath does not utilize the sensor node whose temperature is beyond the maximum threshold limit. The QoS field takes care of successful delivery of packets to sink. The energy field helps to select a neighbor with more residual energy as next-hop relay.

Fig.4 Average power consumption for different data rate

The figure 4 illustrates the average power consumption of different data rate for case 1 to 3. From the obtained results, it is observed that the average power consumption is less in case 1 & Case 2. In case 3 energy increases with data rate. Thus large amount of power is consumed in case 3, thereby reducing the node life time considerably. Furthermore, the routing decisions gets affected due to residual energy and the data avoid passing through the node with lessen energy.

3.3 Lifetime analysis

Figure 5 shows the lifetime analysis at different cases. In case 1, the sensor node works for longer duration compared to other two cases. In case 2 condition, the nodes are influenced by environmental temperature which causes fast discharging of available energy in the battery. If the discharging rate of battery power increases, then the total lifetime of the sensor node gets decreased. In case 3, due to re-routing process the sensor spends more energy for transmitting the data to long distance. As the transmission distance increases, the energy consumption will also remain high. Likewise, if the packet size increases then the energy consumption also increases. Thus the lifetime of sensor node gets reduced in case 3. Moreover, the improper energy calculation of sensor node during route node selection results in rapid death of sensor nodes within the network.

Fig. 5 Lifetime analysis for all three cases

3.4 Delay analysis

The delay modeling is performed at all the three cases and the corresponding result (delay vs temperature) is shown in figure 6. The delay performance was evaluated based on the total number of packets delivered within the specified time period. From the graph, it is observed that the delay is minimum in case 1 as the transmitted data packets reach the destination through the shortest path. So all nodes perform data transmission with minimum delay.

Fig.6 Delivery delay analysis over temperature

In case 2, the delay is high due to external temperature influence on a particular sensor node. This results in the limited operation of the node. At this condition, the data packet transmission will be stopped and the neighboring nodes will update the current temperature value of the affected node. Likewise, in case 3 the sender node will completely reroute to the next shortest path. As the transmission range increases, the delay gets increased during delivery of data to destination node.

Conclusion

As WSN are deployed in unattended areas and are provided with minimum energy for operation. It affects the network's performance and lifetime. Thus EAOPOT routing Protocol was proposed. This protocol mainly concentrated on the effect of surrounding environmental temperature and selects an optimum routing path accordingly. Here temperature, delay, lifetime and power consumption of sensor nodes at three different cases are analyzed. From the obtained results, it was inferred that case 1 results have efficient QoS and increased network lifetime at normal environmental temperature. In case 2, as the temperature increases, the delay gets increased and network lifetime becomes minimum for a single sensor node. In case 3, fully established sensor network was considered. In this case, the environmental temperature influence on the QoS, lifetime, and temperature of sensor nodes was observed. Therefore, the effect of environmental conditions on the performance of sensor node was analyzed.

Declarations

-Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

-Competing Interest

We declare that there is no Competing interests for this article.

-Funding

There is no funding is available for this article

-Authors Contribution

Author one **Ms B Banuselvasaraswathy** is the corresponding author for this article. She carried out the following works: Protocol design, Parameter selection, MATLAB simulation and paper writing. Author two **Dr Vimalathithan Rathinasabapathy**, provided guidance to first author in protocol design, implementation and in article writing.

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Fig.1 Environmental Aware Thermal – Routing (EAT) Protocol

Fig.2 Node Deployment and Network Topology

Fig.3 Temperature variation of sensor nodes at time of t seconds

Fig.4 Average power consumption for different data rate

Fig. 5 Lifetime analysis for all three cases

Fig.6 Delivery delay analysis over temperature

Figures

Figure 1

Environmental Aware Thermal – Routing (EAT) Protocol

Figure 2

Node Deployment and Network Topology

Figure 3

Temperature variation of sensor nodes at time of t seconds

Figure 4

Average power consumption for different data rate

Figure 5

Lifetime analysis for all three cases

Figure 6

Delivery delay analysis over temperature