Application-Prioritized Hierarchical Routing Protocol for Wireless Sensor Networks

Naseeruddin, Venkanagouda C Patil

Abstract*: A novel approach on application prioritization for Wireless Sensor Network (WSN) is proposed in this paper. This approach attempts to modify the existing node structure in the WSN by adding multiple applications on a node and prioritizing them based on available energy criterion to achieve the network performance. For evaluation of the proposed approach three existing hierarchical WSN protocols Low-Energy Adaptive Clustering Hierarchy (LEACH), Distributed Energy Efficient (DEEC) and Threshold Distributed Energy-Efficient Clustering (TDEEC) are modified and performance is analyzed considering five different cases. The modified TDEEC with prioritization approach has shown notable performance improvement in terms of throughput, network stability and network lifetime compared to other protocols considered for the evaluation study.

***Index Terms*: Hierarchical; Lifetime; Priority; WSN; stability,.**

I. INTRODUCTION

The primary purpose of WSN is collecting data, sensing samples within a specific area and transferring these readings to a Base Station (BS) for further processing [1]. The demand for wireless network applications is growing rapidly. The wireless network is deployed to cater for a number of applications. The applications of WSN routing protocols can be broadly categorized as Environment -specific, Task-specific and General [2]. Typical application areas are agriculture, home automation, healthcare, smart cities, and military. Wireless sensing in these areas has ample scope for improving productivity and to provide necessary security to human life in risky or dangerous environments. The protocols used for the WSNs are required to maximize the network lifetime and network stability.The common requirements of a WSN protocol that must be addressed are scalability, dynamic network topology, cost-effectiveness, security, simple and efficient routing mechanisms. A node in a WSN has to be multi-functional, as it needs to sense, process and communicate. A node consists of a micro-sensor, memory, microprocessor, battery and radio transceiver to communicate with the rest of the network. The nodes of a WSN are tightly constrained in terms of memory storage, processing, and the available energy source. Energy constraint is a serious concern in WSN; more than 44% [2] of the work is focused on energy efficiency. Effective utilization of the available energy is the biggest challenge in battery-powered nodes. There are many approaches available for minimizing the energy consumption of a WSN node and increase the lifetime of the WSN. Wireless power transfer [3] and energy harvesting [4] are potential solutions to increase the battery lifetime. Prioritization of application based on the critical attributes or prevailing constraints on the node is an alternative solution that can reduce energy consumption and extend the network lifetime. This paper explores and attempts to extend the approach presented in [5] to increase the network lifetime through the prioritization of the application running on a node.

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II. REVIEW OF PREVIOUS WORK

In WSN, the sensor nodes form ad hoc network for monitoring important parameters like pressure, moisture, temperature, humidity, military surveillance, disaster management and etc., [6]-[7]. The interconnection between nodes and routing gives rise to different types of protocols, namely: flat, hierarchical and location-based protocols. Hierarchical routing strategy is most widely pursued to perform energy efficient routing [8]. Hierarchical routing protocols are scalable and energy efficient [9]. Hierarchical routing protocols have the advantage of convenient topology management and data aggregation [10]. The existing hierarchical protocols in the WSN primarily focus on the efficient routing mechanisms, variations in clustering and data aggregation methods. The LEACH protocol is the first hierarchical routing WSN protocol. The hierarchical protocols Power-Efficient Gathering in Sensor Information Systems (PEGASIS [11]), Threshold sensitive Energy Efficient (TEEN) protocol and Adaptive Threshold TEEN (APTEEN) are evolved from LEACH protocol. These protocols are based on the clustering concept that provides self-organization capabilities in the WSN. Only a few of the proposed protocols in WSN consider applications running on the nodes as an integral part of the WSN modeling. The TEEN [12], APTEEN [13] and Threshold-Sensitive Stable Election –TSEP [14] that employs application based routing in WSN. In this paper, three hierarchical protocols are modified to incorporate the application on the nodes. The protocols considered are DEEC [15], TDEEC [16] and LEACH. The purpose of selecting these protocols is to cover at least one varying aspect of clustering in the existing WSN protocols. On study, it is found that the LEACH [17] is the first cluster based protocol, while DEEC implements the routing based on the residual energy available, TDEEC routing is based on the energy heterogeneity. The DEEC, TDEEC and LEACH protocols are grouped together for the consolidated evaluation and discussions. In DEEC, the cluster heads are elected based on the ratio between residual energy of each node and the average energy. The nodes having high residual and initial energy will normally become a cluster head. The TDEEC introduces the energy heterogeneity by having normal and advanced nodes.

III. METHODOLOGY

The nodes in these protocols are modified to incorporate 'A' number of applications. A random application selection algorithm is added on each of the node that runs the selected application for random duration of time. The application priority in 'A' number of applications is decided based on the minimum energy criterion. Further upon priority activation the node selects and runs the minimum energy consuming application for the specified duration of time.For comparative analysis, initially the modified protocols are allowed to run only random application on each node in the network and related performance parameters are collected. In the next part of the analysis modified protocols run priority application on each node for the specified duration and then shifts to random application selection algorithm. The collected performance data for both cases is then analyzed to validate the proposed novel strategy. For ensuring statistical validity, average values are considered for the discussion. The comparative analysis is carried out in a new form by expressing the percentage difference between with-priority and without-priority protocols under evaluation.

IV. PROPOSED APPLICATION PRIORITIZED HIERARCHICAL ROUTING PROTOCOL

This section describes the proposed application prioritized hierarchical routing protocol for WSN. Table I lists the notations used in describing the proposed protocol.

Table I: List of Notations

Symbol	Meaning
N	Number of sensor nodes
A	Number Applications per node
A_re	Application Reserved Energy
Pec	Percentage of Energy consumption per application per 'Rt'
Rt	Runtime duration corresponding to the application and 'Pec'
Tpe	Total Energy of all applications
Aec	Application energy distribution out of A_re
xWP	Modified Protocol with application prioritization approach
xWOP	Modified Protocol with-out application prioritization approach

A. *Assumptions*

1) The nodes of WSN are deployed randomly by a random process.
2) Number of applications and order of running the application on a node is random.
3) The selection of priority is based on the minimum energy consumption.
4) The radio model used for calculation of energy consumption is first order radio communication model [6].

B. *Flow chart of the proposed protocol*

Fig.1 shows the flowchart of the protocol. The protocol initially deploys the nodes randomly in a specified area called as sensing area. In the following step cluster heads are selected based on the criteria similar to the LEACH protocol. In the next step, the remaining nodes called as normal nodes associate with the nearest cluster head. Each node runs 'A' number of applications. On the activation of the priority, node runs only minimum energy consuming application for the duration 'Rt' and communicates to the associated CH. Further cluster heads aggregate the data and this aggregated data is transmitted to the base station (BS) in the final step. The proposed protocol is categorized into two main algorithms 1) Core algorithm 2) Random application selection algorithm. The core algorithm describes the steps involved in selecting minimum energy consuming application on a node once priority is activated in the network. The random selection algorithm deals with the random selection of application on a node.

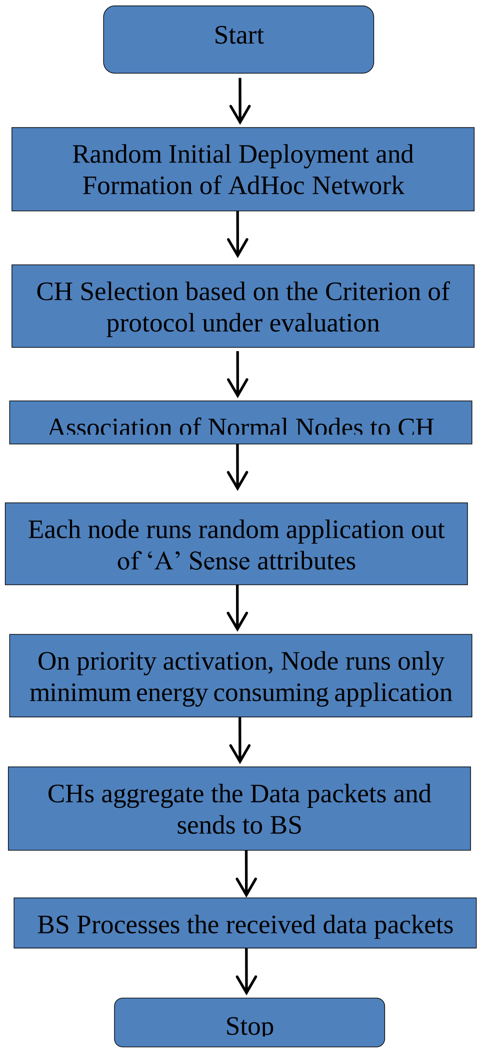

Fig.1: Flow chart of the proposed protocol

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C. Core Algorithm of the proposed protocol

The core algorithm of the proposed protocol is as shown in Fig. 2.The number of applications 'A' running on a node is restricted to a maximum value of 6. The selection of the application priority is based on the energy available on a node and energy available in the network. In initial steps, the algorithm reads and confirms the availability of minimum application reserved energy A_re, total energy consumption Tpe for each node. On the activation of the priority, the algorithms select the minimum energy consuming application. The nodes in the network run this minimum energy application for the duration `Apptime' as computed in Step 8. If the application reserved energy 'A_re' depletes below the 'Tpe' then algorithm shuts down the maximum energy consuming application on each node. Thus, the number of applications running on the node is reduced to conserve the overall network energy. In the present study, only energy constraint is considered as the priority mechanism. The selection of an application or any other node related parameters can be left to the algorithm to decide based on certain wireless network constraints. The primary purpose of the algorithm is to add multiple applications on a node and ensure a priority selection mechanism.

Core Algorithm	
Step1	Random distribution on 'N' sensor nodes
Step2	**for** i=1 to N
Step3	**read** A,A_re,Pec,Rt,Tpe,Aec from the main algorithm
Step4	**initialize** Apptime=0
Step5	**if**((A ,A_re,Tpe are not equal to zero) & (A_re >Tpe))
Step6	**find**(Minimum Energy consuming Application and corresponding Rt,Pec,Aec)
Step7	**if**(mod(current runtime and Rt)==0)
Step8	**Compute**(Apptime=Rt+Current Time)
Step9	**endif**
Step10	**if**(Apptime = = Current Time)
Step11	**Compute** -remaining energy of the present application-step6,Tpe and A_re
Step12	**endif**
Step13	**if(**A_re is less than the Tpe)
Step14	**find** and **shutdown** the maximum energy consuming app and **recompute**: A_re,Tpe,and A
Step15	**endif**
Step16	**else**
Step17	**return** : A_re and Tpe
Step18	**endif**
Step19	**endfor**

Fig.2: Core Algorithm of the proposed Protocol

D. Random Application selection algorithm

Fig. 3 lists the main steps of the random application selection algorithm. This algorithm is developed to justify and validate the performance improvement of the CPHR core algorithm. The random selection of application is a real scenario in the practical implementation. Hence, to account for this practicality the randomness factor is necessary. The only change in this algorithm in comparison to the core algorithm is in Step 6 and Step 14. The algorithm selects an application in a random way. Based on the rate of energy consumption and run time duration, the algorithm computes the remaining energy of a node. If application reserved energy A_re depletes below the total application energy Tpe, the algorithm shuts down the current application and re-computes A_re, Tpe, and A and returns these values to main protocol.

Random Application Selection Algorithm	
Step1	Random distribution on 'N' sensor nodes
Step2	**for** i=1 to N
Step3	**read** A,A_re,Pec,Rt,Tpe,Aec from the main algorithm
Step4	**initialize** Apptime=0
Step5	**if**((A ,A_re,Tpe are not equal to zero) & (A_re >Tpe))
Step6	**Random Selection** of application and corresponding (Rt,Pec,Aec)
Step7	**if**(mod(current runtime and Rt)==0)
Step8	**Compute**(Apptime=Rt+Current Time)
Step9	**endif**
Step10	**if**(Apptime = = Current Time)
Step11	**Compute** -remaining energy of the present application-step6,Tpe and A_re
Step12	**endif**
Step13	**if(**A_re is less than the Tpe)
Step14	**find** and **shutdown** the maximum energy consuming app and recompute: A_re,Tpe,and A
Step15	**endif**
Step16	**else**
Step17	**return** : A_re and Tpe
Step18	**endif**
Step19	**endfor**

Fig.3: Random Application selection Algorithm

V. RESULTS AND DISCUSSIONS

The protocols are under study are tested for different cases using MATLAB 2016b tool. The simulation results of each case are briefly described. Table II shows the specifications of simulation performance parameters for the protocols under evaluation. The major cases/scenarios covered include the effect of variations in the number of nodes, the effect of variations in the number of applications running on a node, the effect of variations in the percentage of energy consumption per duration of time and the effect of variations in the percentage of application reserved energy. Fig.4 illustrates simulation results for the case of the number of nodes N=100, application reserved energy A_re=10%, number of applications A=5.The prefix 'Prior'in the legend mean protocol with application priority and prefix 'Ap/App' mean modified WSN protocol with multiple applications on a node without priority. A comparative performance analysis is done considering the following network metrics:

Network Lifetime: It is defined as the time interval from the start of network operation until the death of the last alive sensor node.

Stability period: It is defined as the interval from the start of the network operation until the first sensor node dies.

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Throughput: Number of packets transmitted to the base station (BS) in an interval.

Table II: Specifications for simulation performance evaluation

Parameters	Value
Number of Nodes 'N'	100-250
Network Area	100mtrs*100mtrs
Sink Location	100,100
Cluster Head(CH) Probability –p	0.1
Initial Energy of the node-Eo	0.5 J
Percentage if the energy reserved for Applications- Th	10% to 50% of Eo
Energy available for routing-Eroute	Eroute=Eo-Th J
Heterogeneous Energy Factor 'a'	0 or 1
Data Packet Size	4Kb
Amplification Energy(Efs)	10pJ/bit/m^2
Energy for Transmission(ETx)	50nj
Energy for Reception(ERx)	50nj
Energy for data aggregation (EDa)	5nj/bit/signal
Number of applications(A)	1 to 6

A. Effect of variation of number of nodes (N)

The number of nodes 'N' is varied from 100 to 500.The consolidated performance effect is shown in Fig. 5 for the specifications of A=5, A_re=0.5, Rt=100-150 rounds, Pec=15 to 20%.The TDEECWP has achieved good network stability as the number of nodes is increased from 100 to 500.LEACHWP and DEECWP have shown improvement for low density of nodes; as the density of nodes increased the network stability degrades. The network lifetime of TDEEC WP and DEECWP is better than the TDEECWOP and DEECWOP. The throughput performance of LEACH WP remains consistent as the number of nodes is increased, whereas in case of TDEECWP, DEECWP the throughput falls. From the performance in terms of number of cluster heads (CH) it is observed that TDEECWP and DEECWP generate a lesser number of CHs, while LEACHWP CHs increase when the number of nodes is increased.

B. Effect of variation in the number of applications (A)

Fig. 6 shows results of the simulation evaluation for the specifications: A_re=0.5, N=100, Pec=10-15%, Rt= 30-45 rounds. The number of applications 'A' is varied from 3 to 5. As the number of applications running on a node is increased, the TDEECWP performs consistently in terms of network stability and the network lifetime. The throughput for DEECWP, TDEECWP increases as the number of applications is increased. This indicates the positive effect of prioritization. The number of CHs has not shown any significant difference.

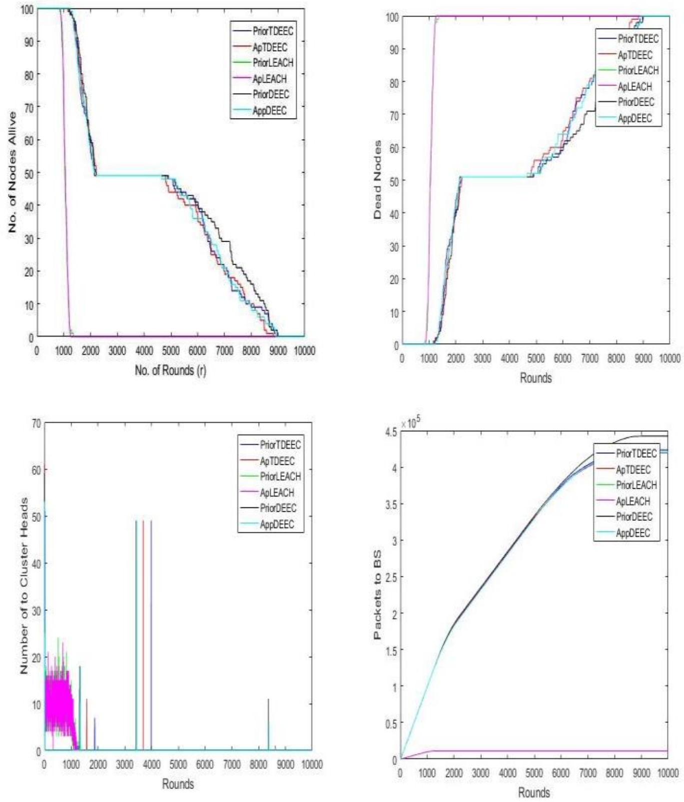

Fig.4: Comparison between LEACH, TDEEC and DEEC with-priority and without-priority (Case N=100, A_re=10%, A=5)

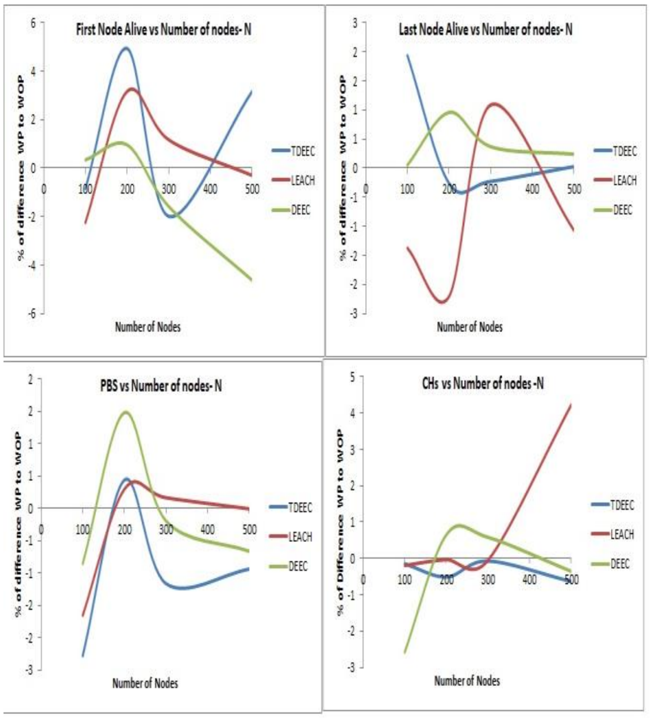

Fig.5: percentage difference on the performance between with-priority and without-priority protocols for varying number of nodes 'N'

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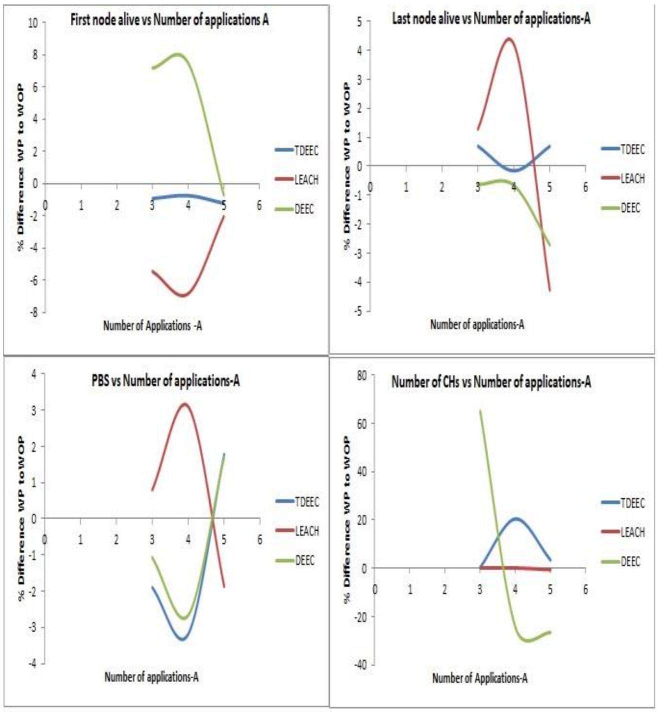

Fig.6: percentage difference on the performance between with-priority and without priority protocols for varying number of applications 'A'

C. Effect of variation in the percentage of energy consumption per application per duration of time (Pec)

The 'Pec' is varied randomly. The effect of variations of percentage of energy per application per Rt duration is as shown in Fig.7 for the specifications: A_re=0.5, N=100, A=5, Rt= 30-45 rounds. The network stability achieved by TDEEC WP is better as the Pec is increased, DEEC WP initially shows improvement and later on network stability falls. There is no significant difference in terms of network lifetime except for some particular value of 'Pec'. The throughput shows an increasing trend as the 'Pec' is increased; this is due to the fact that the prioritized nodes have more energy than the non-prioritized node. The DEECWP has generated minimum number of CHs while having good throughput and network lifetime.

D. Effect of variation in percentage of application reserved energy (A_re)

The number of applications reserved energy `A_re' is varied from 10% to 50%. Fig.8 shows the effect of varying A_re for the specifications: N=100,A=5,Pec=10-15%,Rt= 30-45rounds. The network stability shows variations in the performance for varying A_re for LEACHWP, TDEECWP, whereas for DEECWP it drops. The Network lifetime improves as the percentage of A_re increases. The throughput slightly drops as A_re increased. The number of CHs starts to decrease as the A_re increased.

E. Effect of variation of Run-time Duration 'Rt'

The run-time duration 'Rt' affects the 'Pec' of an application. Hence, 'Rt' effect on the performance is also analyzed. Fig .9 gives the effect of 'Rt' on the performance of protocols under study. The specifications: A_re=0.5, N=100, A=5,Pec=15-20% are considered for the simulation study. The network stability improves for TDEECWP and DEECWP protocols as `Rt' is increased, TDEECWP shows significant improvement in terms of network lifetime at Rt=250sec, DEECWP shows steady improvement in the network lifetime as Rt is increased.

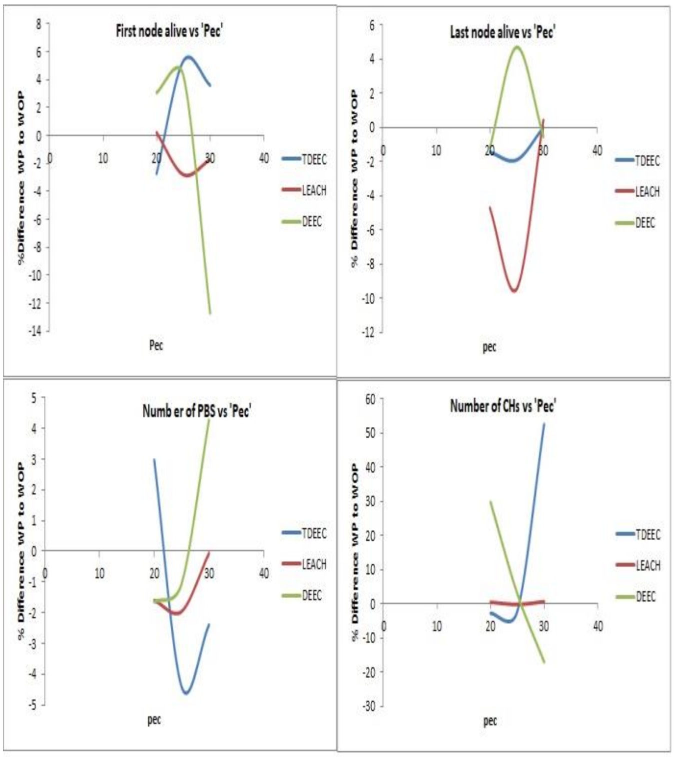

Fig.7: percentage difference on the performance between with-priority and without-priority protocols for varying percentage of 'Pec'

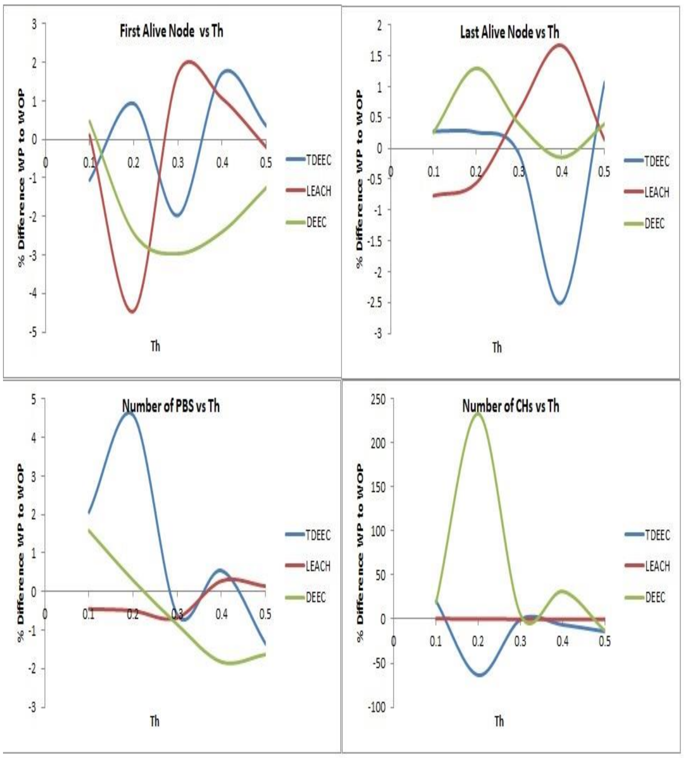

Fig.8: percentage difference on the performance between with-priority and without-priority protocols for varying application reserved energy 'A_re'

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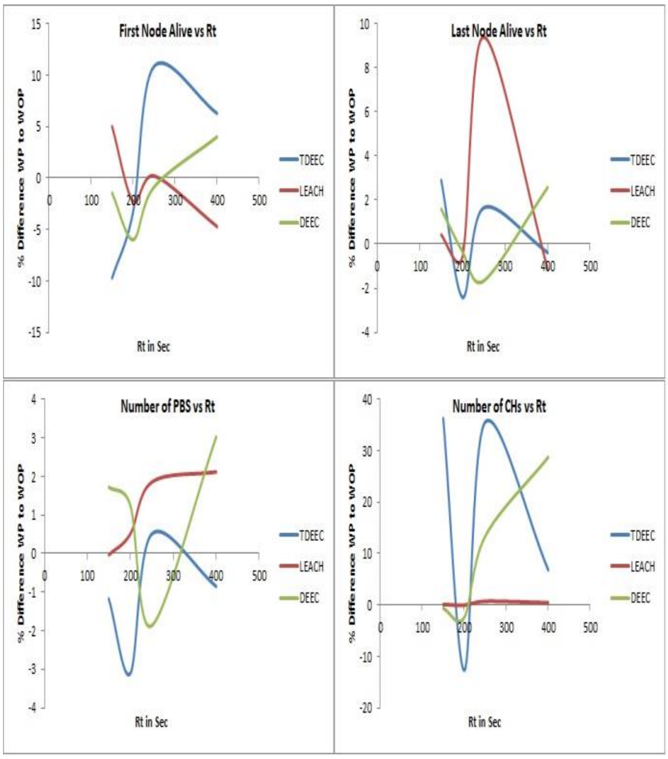

Fig.9: percentage difference between with-priority and without-priority protocols for varying run-time duration 'Rt'

The LEACH protocol shows varying performance. In terms of throughput, LEACHWP has shown consistent improvement in the performance, while DEECWP shows improvement beyond Rt=300sec. The number of CHs is more for DEECWP as 'Rt' is increased, while TDEECWP shows a decreasing trend. The LEACH protocol is consistent in terms of the number of CHs.

VI. CONCLUSION AND FUTURE SCOPE

In this study, a novel approach of adding multiple applications and prioritizing them is presented and evaluated for WSN. Three existing hierarchical WSN protocols are modified and their routing performances are studied under different scenarios. A novel method of comparison is also introduced and elaborate performance analysis is done. The criterion for prioritizing the application is restricted to available energy to run an application. In the future, this work can be extended to include prioritization based on various parameters of the WSN and hence routing can be made more energy and bandwidth efficient.

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