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# Energy Efficient Clustered Architecture in Cognitive Radio Network with Optimum Sensing Time

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***Abstract -*** *Cognitive Radio (CR) is an upcoming technology for spectrum usage optimization in wireless communication. Energy Detector(ED) with Cooperative Spectrum Sensing (CSS) is thepreferred detection methodology for CR system. Selecting a appropriate detection threshold for ED is essential to achieve the target Detection Probability (Pd). This work proposes an energy efficient cluster-based CR with optimum sensing time. Clustering organizes Secondary Users (SUs) into sets in order to improve the throughput and stability of Cognitive Radio Networks (CRN). By considering various affecting factors, to establish the optimal clustering is a challenge. This paper is focused ontwo phase Cluster Head (CH) selection based partition clustering algorithm to obtain the balanced clustered architecture with optimum energy efficiency. The result achieved with this clustering verifies the improvement in Pd and energy efficiency of CRN with optimum Sensing Time (Ts).*

## I. I.INTRODUCTION

Wireless communication systems experiencing a great advancement of radio communications techniques which in turn amplified the need of spectral resources [1], to manage the demand “Federal Communication Commission (FCC) introduced new policies for spectrum management and allocation” [2]. CR is one of the techniques considered for optimal spectrum access to resolve the issues of congestionas well as spectrum under-utilization issue of licensed/ Primary User (PU) [3]. CR users are competent enough to access the temporarily unused licensed PU-spectrum for their own communication. Using CR, utilization time of licensed spectrum is increased and idle time of spectrum is reduced and ratio of bits/sec/Hz is improved which in turn improves network spectral efficiency and also it helps to improve Cognitive Radio Network (CRN) throughput. For Secondary use of spectrum, spectrum sensing is significant in CRN.

“Matched filter, Energy and cyclostationary detection are considered as the best basic spectrum sensing methods”[4]. ThoughED method is simple in implementation which works without predefined knowledge of the PU, its accuracy is less compared to other two methods. Because performance of spectrum sensing by ED is affected by shadowing and fading effects in the sensing channellink between the PUs and SUs. Cooperative Spectrum Censing (CSS) mitigates the impact of these effects efficiently by using integral multiuser CR network. Also, CSS can improve the Pd of PU signals, at the cost ofTs latency, control signal overheads and large energy consumption during decision reporting to Fusion Centre (FC) from SU about PU status [5].

Cluster imparted on Cooperative Spectrum Sensing (CCSS) scheme is a resolution for issues in CSS. Cluster is a group of evenly distributed SUs controlled by CH. Uniform distribution of SUs minimizes time overhead, packet collision, channel congestion as well as signalling overload of FC, which in turn enhances overall system sensing performance and energy efficiency of CRN. Although, clustering is advantageous viz. stability, scalability and integrity in CR networks, still dreadful challenges of clustering are found [6]. “The Low Energy Adaptive Hierarchy (LEACH) was a base line distributed clustering scheme for WSNs” [7]. For dynamic channel shifting of CRSNs, a spectrum conscious clustering protocol “Cog-LEACH” was implemented based on LEACH [8]. “A low-energy adaptive uneven clustering hierarchy (LEAUCH)” deliberated the advantage of the vacant channel resource to shrink the energy consumption [9]. Many researchers have worked to implement clustered architecture in CRN to achieve better result; brief review of existing state of the art is discussed below.

NafeesMansoor et.al [10] proposed ‘cluster-based architecture for CR ad-hoc networks’, clustering was based on the spatial variations of spectrum opportunities. SUs sensing similar free channels were grouped into the same cluster. Maximum edge biclique problem concept was used in cluster formation. Maximum 500 SUs were clustered under 23 clusters using this method. Further a Two-level Cluster-based CR Sensor Network was proposed in [11], with fusion MAC design for the CRN that guarantees consistent and well-timed delivery of data. The suggested protocol divides the MAC-layer task into two domains: “uni-channel intra-cluster” and “cognitive inter-cluster domains”. Experimental results shows, 93% of success rate in packet delivery. Authors have modified the work with super-frame structure and topology maintenance protocols in [12], revised work is analysed w.r.t number of SUs participating in clustering, number of cluster formed and related time constraints in CRN. Modified algorithm optimizes packet transmission delay in the range of 5ms to 10ms for maximum number of users 250.

During sensing in clustered CRN maintaining Pd is necessary. "CSS based on signal decomposition and K-medoids clustering algorithm"[13,14] is proposed to recover weak sensing performance and accuracy in sensing with low signal-to-noise ratio (SNR). Initially for lesser number of SUs "feature extraction of sampled signal with empirical mode decomposition and matrix decomposition-recombination" is used, further extracted features are characterized using the K-medoids clustering algorithm. Observed result shows, Pdwas improved in the stable range of 0.25 to 1 for variation in SNR -16 to -14dB. In [15] Shunchao Zhang et.al used Fuzzy c-means clustering to maintain Pd with variation in number of SUs. Initially the signal detection problem was converted to geometric problem by using information geometry theory. Then,statistical characteristics of the signal were extracted with geometric tools. Based on extracted characteristics, the appropriate classifier is trained for spectrum sensing with "fuzzy c-means clustering algorithm". Result indicates steady Pd in the range of 0.15 to 1 for number of SUs ranging from 2 to 10.

For faster detection along with high detection probability, multiple reporting channel based clustered architecture in CSS is used by Mohammad Amzad Hossainet.al[16] . This technique is focused on reducing SU to CH and CH to FC reporting time which gives opportunity to increase sensing time. Increased Ts improves Pd and reduced reporting time helps to minimize overall delay in CRN. Reporting delay was reduced in the range of 80 to 250 ms and Pd 0 to1 for 4 numbers of SUs in the cluster. In [17] "optimal linear weighted clustering is proposed for CSS. In this method, dynamic weight values were assigned to SUs according to the sensed SNR and the previous sensing accuracy of node". After clustering,for collecting the local sensing data,CHs were elected from SUs with the greater channel characteristics. Result shows good Pd ranging from 0 to 1 with reduced error probability up to 0.15 to 0.25 for variation in number of SUs in the range of 10 to 60. In multi-antenna SUs,Shunchao Zhang et. al[18] used "Riemannian Distance-based K-medoids(FRDK)" in CSS to fuse sensing data from multiple antennas. This fused and processed data is submitted to FC. FC use this data for prediction of PU status. Using this method sensing delay was reduces up to 1s with Pd ranging from 0.1 to 1 for SNR -12dB.

The purpose of clustered architecture is to reduce delay and maintain energy efficiency in the network to improve life time of CRN. With reference to comparative study of clustering techniques used in CRN. There are three widely used clustering techniques viz. Low Energy Adaptive Clustering Hierarchy (LEACH), K-means and K-medoid. LEACH is a distributed clustering algorithm where each node declares itself as a CH based on some probability 'P'. Here selection criteria for CH are not stringent. In case of high SNR levels in the network LEACH performance is good. But in case of noise environment proper selection of CH is essential. In K-means clustering CH are selected based on two selection criteria 1. Sensed energy level at node 2. Distance of node from FC. This ensures minimum energy consumption and long network life. Moving ahead K-medoid is a improvised version of K-means clustering algorithm. K-medoid gives better scalability even in larger network with more number of SUs. Also, It is superior than other two algorithms in presence of noise environment and execution time is very less [12-15].

By considering above comparative analysis and review of literature it can be concluded that K-medoid is best performing technique but it can be modified to achieve healthier and robust CSS. Proposed optimization work in this paper is focused on K-medoid clustering architecture. The main purpose of proposed optimization work in this paper is to design an improved K-medoid clustering CSS with optimized dynamic sensing threshold ED technique and optimized sensing time, to improve Pd and energy efficiency of the network. Remaining part of the paper is divided in to three main sections. Section II illustrates the methodology used in proposed optimization technique. Section III confers about the results achieved and its comparative analysis. The last section IV gives conclusion about the proposed optimization work and its achieved results.

## II. METHODOLOGY

For prosed optimization work crucial network parameters as SNR range, range of Probability of False Alarm (Pf), Sensing Frequency (F), Total Sensing Frame Time (T) are considered as per IEE802.22 standards for CR [19]. Total number of users (SU+PU) and network area are considered by concerning Pico–cell network criteria [20]. The main optimization work is preceded with three phases.

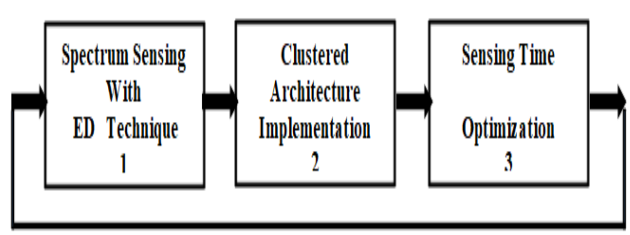


**Figure1: Design flow of proposed optimization work**

Figure1 shows the flow of proposed optimization work with consideration of its phases. In first phase basic ED is implemented from SUs to sense PU spectrum. Performance of ED is susceptible to environmental noises in the network as fading, shadowing, lightning etc. Hence to improve the performance of ED w.r.t Pd and add the robustness in the spectrum sensing is very essential as it is a foundation for any further optimization in CSS. Considering this fact, during first phase the proposed work is focused on optimum selection of threshold by adding dynamicity to the threshold based on SNR and Pf values. Output of first phase acts as a input to second phase. Based on estimated energy levels and inter nodal distances clustered architecture is implemented. Now sensing and reporting of each node is restricted within its cluster which reduces signalling overload and communication delay. Still there is scope to improvise the performance of clustered architecture w.r.t. sensing accuracy by maintaining optimum Ts. Ts is an additional drain in CRN time frame in comparison with primary network, which cannot be dropped down to zero. Optimization of Ts is the only way to limit the delay as well as maintain the sensing performance. Hence third phase of optimization Ts is optimized with bisection technique. This optimum Ts is used in every next sensing cycle. The detailed algorithm of each phase is explained in next part of methodology.

### *A. Spectrum sensing mechanism using dynamic threshold.*

Dynamic Threshold Sensing: The base of network is designed by plotting random number of nodes with random energy in MATLAB GUI environment.Optimization process starts with spectrum sensing with ED technique, but the irregularity related with noise levels influences on the detecting execution for recognition of PU status and free band accessibility. Hence, the threshold level related with PU signal detecting criteria is required to be dynamic for better execution in the detecting methodology. Steps followed for setting the dynamic threshold are as below.

It is assumed that initially all SUs are participating in spectrum sensing. Hence received signal at individual SU when PU is absent and PU is present is given by equation1 and 2 respectively by considering hypothesis $H_0$ and $H_1$,

$$x(t)= r(t)\ldots\ldots\ldots\ldots H_0 \quad (1)$$

$$x(t)= h(t).s(t)+r(t)\ldots\ldots\ldots\ldots H_1 \quad (2)$$

Where r(t) is 'white Gaussian noise' and s(t) is received PU signal.

Consider L number of samples is present for sensing then test statistic is given by,

$$X=1/L \sum_{i=1}^{L} |x(t)|^2 \quad (3)$$

Now, X is estimated as a Gaussian distribution by using'central limit theorem' as shown in equation4

$$X \sim \begin{cases} N\ (L,2L)\ldots\ldots\ldots\ldots H_0 \\ N\ (L(1+Ɣ),\ 2L(1+Ɣ)^2\ldots\ldots\ldots\ldots H_1 \end{cases} \quad (4)$$

It is considered in proposed optimization work that, before clustering M number of SUs is participating in sensing Hence probability of detection corresponding to $i^{th}$ SU is given by

$$P_{di}= (Ɣ \geq ʎ|H_1)= Q\left[\frac{(ʎ-(L(1+Ɣ))}{(\sqrt{2L}*(1+Ɣ))}\right] \quad (5)$$

Where Q[.] indicates Q-function Ɣ is signal to noise ratio and ʎis sensing threshold.(i=1,2,3……M-1)

Similarly, probability of false alarm of $i^{th}$SU is given by

$$P_{fi}= (Ɣ \geq ʎ|H_0)= Q\left[\frac{(ʎ-L)}{(\sqrt{2L})}\right] \quad (6)$$

There are two main mechanisms of threshold based on constraints considered for threshold estimation.If predefined range of Pd is used to maintain acceptable error rate then threshold is known as Constant Detection Rate (CDR) threshold. If given range of Pf is considered for threshold setting then threshold is known as Constant False Alarm Rate (CFAR) threshold. Proposed optimization work is focused on maintaining target Pd as maintenance of reduced error rate is already taken care by clustered architecture. Hence by concerning CFAR mechanism, improved threshold is estimated with dynamic limits, where variation in threshold is dependent range of Pf from 0.01 to 1 as per IEEE 802.22 standard[19]. In this calculation Q function is utilized to compute limit. Subsequently this limit estimation is evaluated utilizing Marcum Q work given by,

$$ʎ = (\sqrt{2L}*Q^{-1}(P_f)+L) \quad (7)$$

The dynamic threshold-based sensing is performed which is further embedded in delay optimization method.

### *B. Design of Modified Clustered Architecture.*

#### *a) Designing Clustered Architecture for Random Distribution of Nodes In The Network.*

For delay reduction, distance between SUs to base station is important because with distance, reporting time will be increased hence network architecture is important factor in optimization. Clustered architecture reduces signalling overload from base station and also even distance will be maintained between node and decision centre. Hence here nodes are divided in clusters by using K-medoid clustering which gives better results than other clustering techniques.

The K-medoid is improved version of K-means partition clustering algorithm. Both algorithms are aimed at minimizing the error during clustering. In noisy environment K-medoids algorithm has stable performance than K-means algorithm. In K-means algorithm, random means are chosen for clustering but in the K-medoids, medoids are chosen with predefined criteria. A medoid is aentity of a cluster, with typical minimal dissimilarity to all other nodes in the cluster. In proposed modified clustering approach the information of distance of each node from its neighbor is considered.

The algorithm has two main steps:

**FOUNDATION-STEP:** This step consecutively selects K "centrally located" entities, as foundational medoids.

**SWAP-STEP:** The objective function is optimized by swapping elected entities in step-I with unelected objects, this is iterative till the objective function become convergent [21].

***b) Base algorithm for K-Medoid:***

1. Select K' random SUs as the foundational medoids from total K SUs of the network.
2. Associate each SU to the closest CH by using distance metrics.
3. Calculate the swapping cost $TC_{ih}$, for each pair of selected $SU_i$ and non-selected $SU_h$.

If $TC_{ih} < 0$, I is replaced by h.

4. Repeat the steps 2-3 till network become steady[21].

The selected CH will communicate with the SUs present in the range of communication. The distance based allocation of ordinary SUs under specific CH is considered where, CHs have appropriately less distance from allocated SUs.Hence less distance is the important criteria to become a cluster member under particular CH.

***c) Application of Two stage algorithm for clustering:***

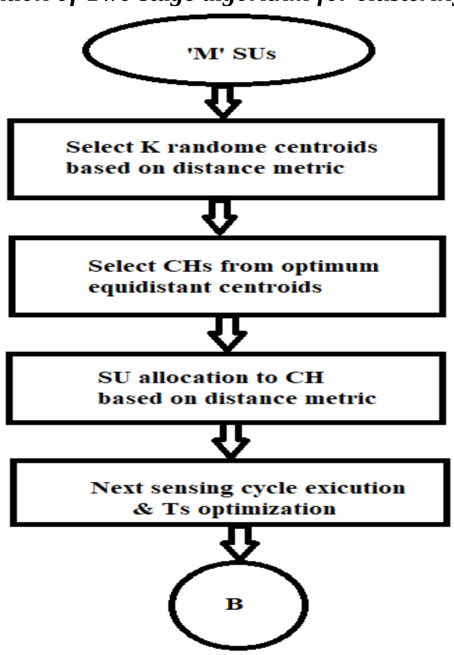


**Figure2: K-Medoid clustering flow graph**

1. For clustering of SUs in CSS as shown in figure2, Select random nodes as CH (centroids) at initialization phase of network.Then again dissimilarity between selected centroids is compared to select optimum centroids as CHs. After finalization of CHs based on distance metric all remaining SUs are allocated under each CH. Distance metric is as follows
2. If $D_{in} < D_{jn}$, Associate SU node with i

Where, i and j are CHs selected, n is common node in communication range of both CHs with distance D.

After allocation swap cost of each allocated SU under cluster is compared with unallocated SUs and swapping of SUs is done if cost is less than zero. This process is continued till all allocations remain consistent. After successful clustering the process of optimization is continued with next sensing cycle for optimization of Ts to optimize energy efficiency of the network.

***d) Algorithm for Optimized Sensing Time.***

Clustering of SUs in CRN reduces signaling overload and communication delay with even communication distance. But in CSS if Ts is static then it augments significant delay in every sensing cycle. But during high SNR of received signal at SU, accuracy of sensing can be maintained with optimum selection of dynamic Ts. Hence by adding optimization to Ts the performance of dual-phase K-medoid clustering. Here, Ts is optimized based on energy consumed during each cycle such that it will maintain the energy efficiency of clustered architecture. Bisection method is used here to optimize Ts value. In second part of methodology delay reduction is done with sensing time.Figure3 shows flow graph of bisection method of optimization

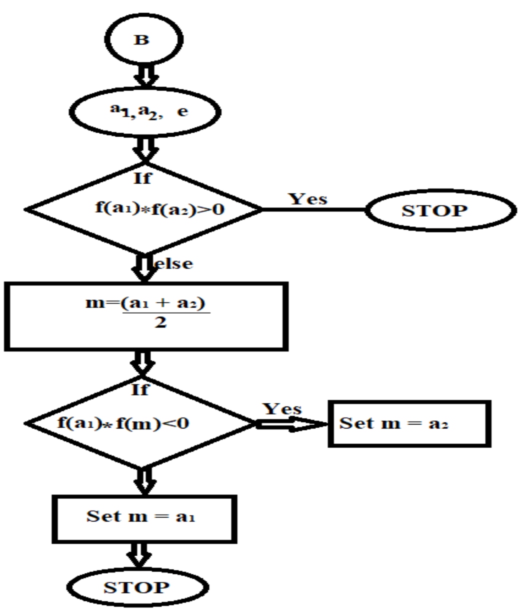


**Figure3: Bisection optimization method flow graph**

As shown in figure3 bisection method has three inputs $a_1$,$a_2$, and e where $a_1$,$a_2$ are randomly selected roots of continuous function considered for optimization and e is error limit. Random roots are selected with opposite signs (+ -) such that $f(a_1)* f(a_2) <0$. Then every random root is compared with mid-point of both roots 'm'. Root having similar sign with m is replaced by 'm' itself. By this way, search intercept of objective function is reduced to half. This process is continued till multiplication of both root functions become zero. When this situation arrives then it is considered as optimum root of objective function under optimization [22].
In this optimization work energy efficiency is considered as objective function in bisection method. Here Ts value is estimated such that it will maintain the desired energy efficiency of the network.

By applying above algorithm on received signal strength Ts is optimized as below.

Defining initial sensing time.

Frame time(T)= PU idle time (7)

Sensing time (Ts)=(T- Ts)/K (8)

Application of bisection in Matlab environment to estimate optimum Ts (root of bisection)

$\eta$(t)= bisection ($a_1$,$a_{2,}$e) (9)

Here $a_1$,$a_{2,}$e are predefined and $\eta$(t) is energy efficiency. With this known value of (t) Ts is estimated so that optimum energy efficiency is maintained.

## III. RESULT AND DISCUSSION

Initially CR network environment is generated in MATLAB GUI with random energy allotment. The network of random plot of nodes with geometric area consideration of 1000*1000 meters is represented in figure4

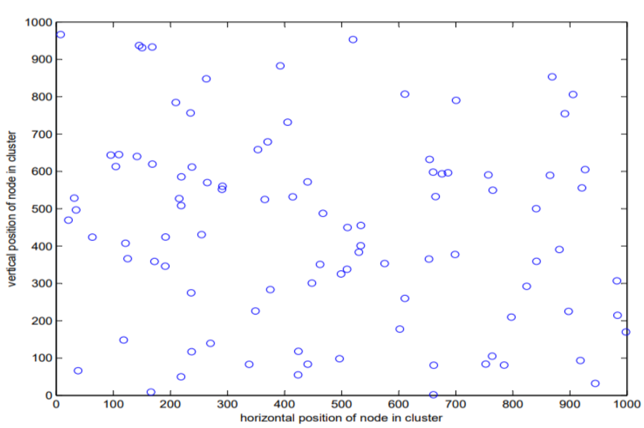


**Figure4: Base network for cognitive radio**

### *A. Designing Clustered Architecture For Even Distribution Of Nodes In The Network.*

Modified clustering algorithm divides nodes in different clusters based on number of alive nodes during clustering, distance from base station, distance of each node from cluster head. Cluster heads are elected based on their distance from each SU and also from other elected CH. The network scenario is dynamic and continuously changing. Clustered architecture designed with alive nodes is represented in figure5.

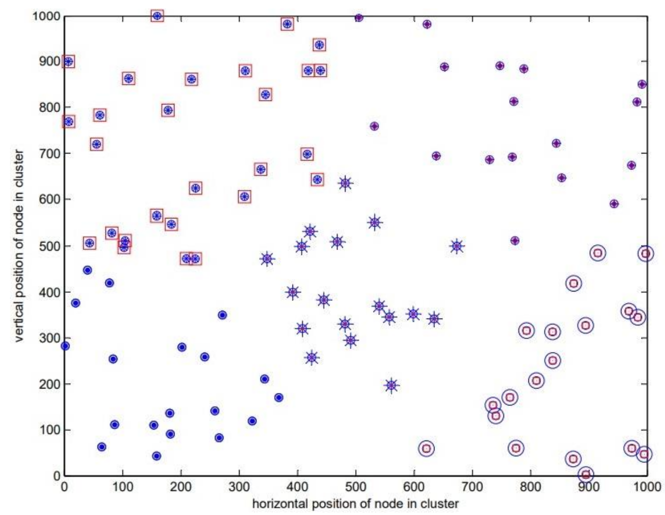


**Figure5: Clustering of nodes**.

### *B. Comparative Analysis for ROC Curve PdVs Pf*

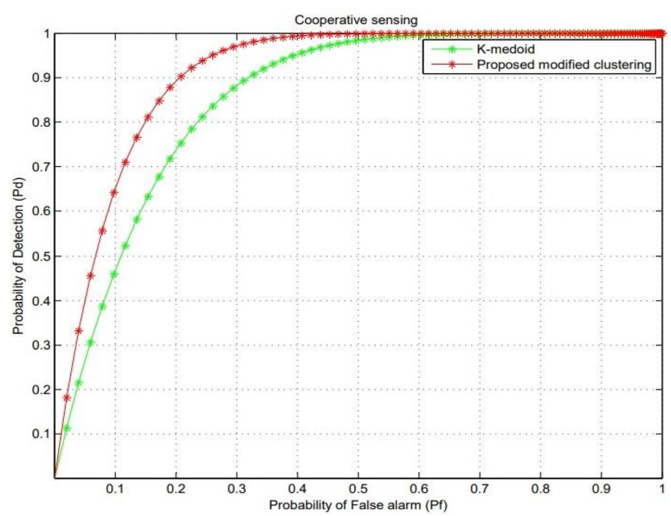


**Figure6: ROC curve PdVs Pf**

Figure6 represents the comparative analysis of ROC curve for simple K-medoid clustering algorithm and proposed energy efficient, Ts optimized clustering algorithm. The range of Pfis predefined as per standards of IEEE 802.22[19]. As can be seen here, the Pd of siple K-medoid algorithm ranges from '0 to 0.7' for rage of Pf '0 to 0.2' where same range of Pd '0 to 0.7' is achieved in proposed modified clustering withreduced Pf range '0 to 0.1' and for pf 0.1 to 0.2the Pd is suddenly increased up to 0.9.Table1 indicates the difference between the performance of both the clustering methods.

**TABLEI: ACHIEVED Pd W.R.T. Pf.**

| Pf RANGE | SIMPLE K-MEDOID (ACHIVED Pd RANGE) | PROPOSED MODIFIED CLUSTERING (ACHIVED Pd RANGE) |
|---|---|---|
| 0 to 0.1 | 0 to 0.5 | 0 to 0.65 |
| 0.1to 0.2 | 0.5 to 0.7 | 0.65 to 0.9 |
| 0.2 to 0.3 | 0.7 to 0.9 | 0.9 to 0.99 |
| 0.3 to 0.4 | 0.9 to 0.95 | 1 |

The achieved range of Pd w.r.t Pf in the table1 clearly indicates that proposed modified clustering algorithm outperformance the simple K-medoid algorithm.

### C. *Comparative Analysis For Energy Efficiency Vs Optimum Sensing Time*

Tsis a critical parameter in CSS as it affects directly or indirectly on accuracy, delay and energy efficiency. Optimum value of Ts maintains accuracy and delay in sensing which in turn maintains energy efficiency of whole system. Hence analysing optimized Ts with respect to energy efficiency is essential. In proposed modified clustering bisection method is applied on cluster during sensing for optimizing sensing time. Also two phase selection of CH is done in proposed modified clustering. Clustering improves overall energy efficiency of a network by reducing signalling overload from base station and cluster head and also reduces delay with evenly distributed nodes, simultaneously bisection method reduces Ts within cluster and overall energy efficiency.

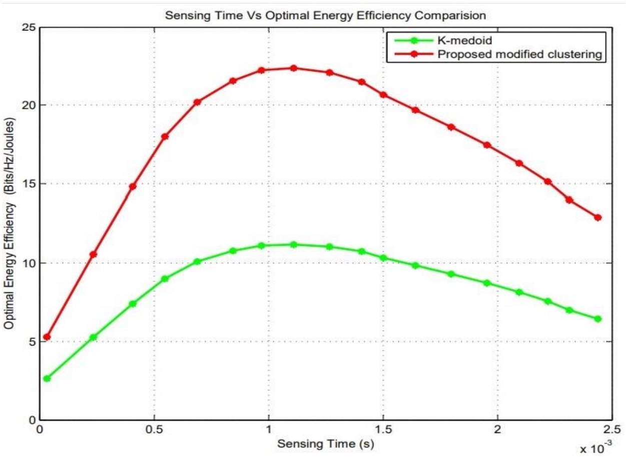


**Figure7: VsTs.**

A. Figure7shows graph of achievable $\eta$with respect to Tsusing traditional K-medoid clusteringand proposed modified clustering. Consider table2 for detail comparative analysis of both the methods of optimization.

**TABLE II: ACHIEVED $\eta$ W.R.T. Ts**

| Ts(ms) | SIMPLE K-MEDOID Achieved $\eta$ (bits/Hz/J) | PROPOSED MODIFIED CLUSTERING Achieved $\eta$ (bits/Hz/J) |
|---|---|---|
| 0.1 | 3 | 5 |
| 0.5 | 7 | 17 |
| 1 | 12 | 22 |
| 1.5 | 10 | 21 |
| 2 | 8 | 17 |
| 2.4 | 7 | 13 |

With reference totable2 it is observed that for same Ts value proposed modified clustering algorithm achieves improved value of $\eta$. Without application of bisection technique in clustering $\eta$ is very poor (3 to 12 bit/Hz/Joules) with overall range of Ts (0.1to 2.4ms). But after application of bisection average energy efficiency is improved from (5 toto22 bit/Hz/Joules) with same short range of optimized Ts and after peak value of $\eta$ efficiency lowers down up to 13 bit/Hz/Joules because, increased Ts above its optimum value adds significant delay in communication which ultimately reduces$\eta$ .This validates the appropriate performance of modified clustering technique in this paper. Proposed optimization technique has improved $\eta$ by 55% than traditional K-medoid clustering for same range of Ts.

## IV. CONCLUSION

In energy efficient clustered architecture with optimized sensing time, simple K-medoid clustering is modified with two phase selection of CH. This confirms the even distribution of CH and SUs in the CR network. To improve the energy efficiency of proposed method, Ts is also optimized using bisection method. From achieved results and comparative analysis it is observed that, proposed clustering method achieves better Pd than traditional K-medoid clustering algorithm for same range of Pf. Pd is reached to its maximum value 1 for very less Pf i.e.0.4. This validates the improved accuracy of proposed technique. Also energy efficiency of modified clustering technique is improved by 55% than traditional K-medoid clustering. This validates the improved performance of proposed modified clustering algorithm as per defined objective to improve $\eta$ with optimized Ts

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