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Cognitive scheme for energy conservation during delays in MANETs

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Abstract

Bandwidth scarcity has become a major issue in advanced communication age. Due to the lack bandwidth data transmission gets delayed. Due to the delays, a lot of energy is wasted by the nodes of a network. This problem becomes even bigger in a Mobile Ad hoc Network (MANET), where nodes are densely deployed and a lot of data transmission occurs. Working on the same frequency band and limited bandwidth with other nodes causes a lot of congestion and thus delays. Cognitive Radio ad-hoc networks provide a solution to this network scarcity problem by identifying a neighboring (unlicensed) frequency band for data transmission using the dynamic spectrum access (DSA) process. The challenge is to identify the frequency band with holes so that, we do not disturb the Primary User's communication. To achieve that, a Cooperative Spectrum Sensing (CSS) technique is used to sense the presence of PU, as CSS is reliable than standalone Spectrum Sensing (SS) techniques. For final decision making on the presence of PU at the fusion centre (FC) an artificial neural network-based technique with 98.2% accuracy is used. The technique used is scalable to conquer the problems of a dynamic MANET. The results when compared with AODV shows improvement. The delay has been removed by hoping the data on the empty frequency channel identified by the technique. The route and network lifetime have increased significantly. Throughput of the system has also improved system by 2%.

Keywords: *MANETs, Cognitive radio ad-hoc networks, Cooperative spectrum sensing, ANN, AODV, Spectrum sensing*

Introduction

The bandwidth availability is limited on MANETs and the amount of data is increasing [1] [2]. Channel scarcity is a big concern as the data increases [1]. Limited bandwidth causes congestion. Higher congestion leads to delays or even packet losses if the Time to Live runs out [3][4]. Delays cost a lot of energy. Throughput is also decreased as time is wasted and routes break due to high energy consumption per packet delivered [1][3].

An analysis was done on the AODV [5] routing protocol to determine the energy losses caused during a communication. A simulated environment was created with the help of MATLAB and Qualnet [6]. Random nodes were deployed and the simulation was done for source to destination transmission. The energy consumption was divided into two parts. First is the energy consumed by every hop during transmission (for receiving the data from previous node and then forwarding it to the next node). Second the energy consumed while an intermediate node was idle due to delay and waiting for the packets to arrive in an ongoing communication.

The resulting graph in figure 1 and figure 2 shows the energy consumed by hops and delays respectively. AODV always chooses the shortest path. The path selected has the least number of hops to the destination. So, the first selected route consumes ~6.3% of route energy for hops and ~3.7% due to delays with a total of ~10% energy consumed by the running route as shown in figure 3. The first route runs for

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12 iterations before it runs out of battery and then the second route is selected and so on. The throughput provided by the system is ~93% considering no packets were dropped due to delays.

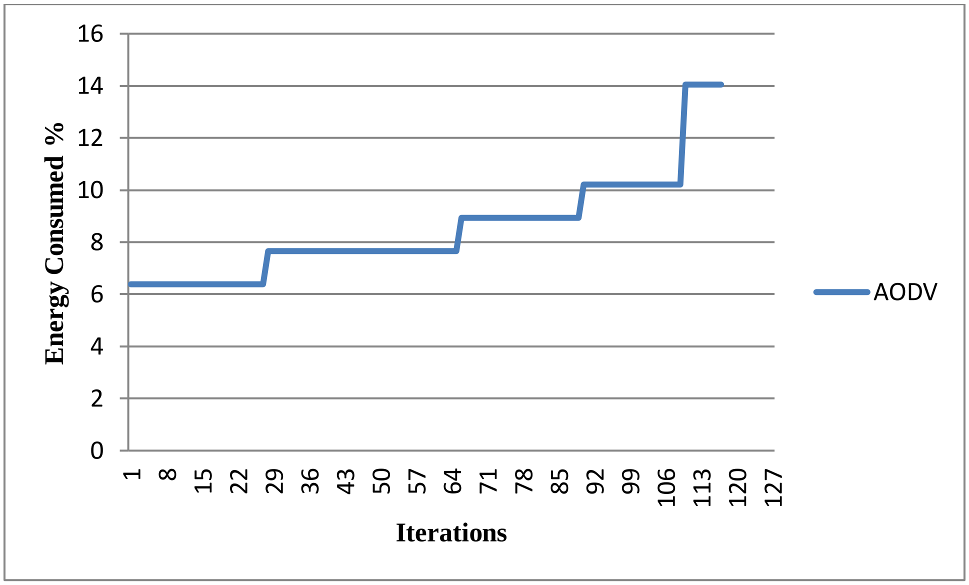

Fig 1. Energy Consumed by hops

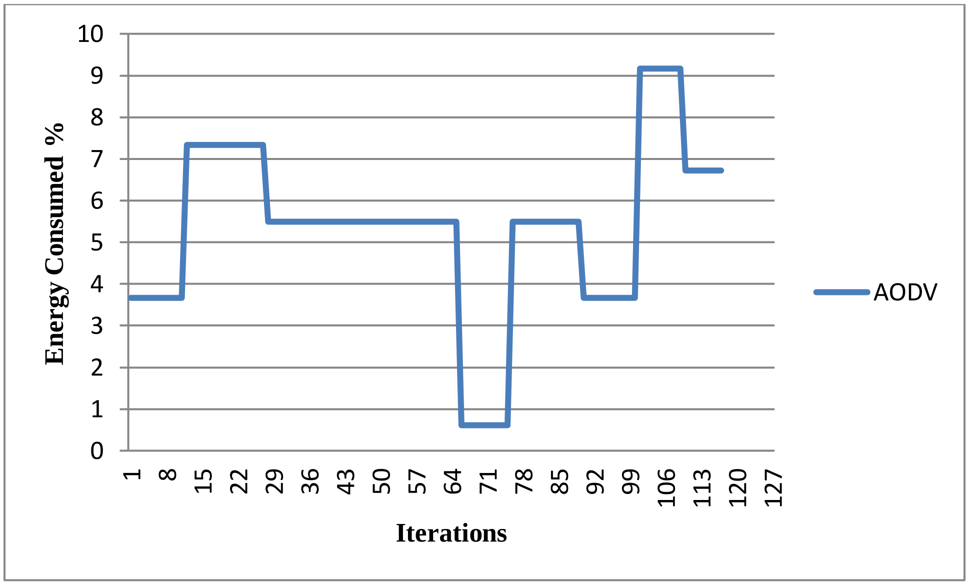

Fig 2. Energy Consumed by delay

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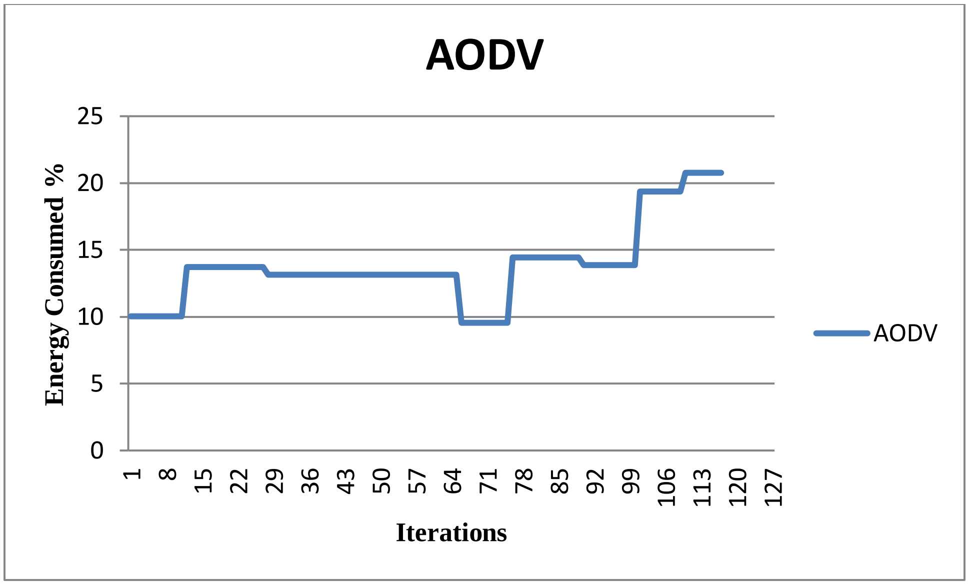

Fig 3. Total energy consumed by running route

The first type of energy consumption is necessary and cannot be avoided but the second type of energy consumption is unnecessary and should be removed [1].

To solve this bandwidth scarcity problem Cognitive Radio is an efficient technology [4] [7]. The unlicensed user known as the secondary user (SU) is allowed to dynamically use the idle spectrum licensed to primary user (PU) in Cognitive Radio Ad hoc Networks (CRAHNs) [4] [8]. Determination of spectrum holes is very important. Spectrum sensing process thus plays an important role in identifying the spectrum hole [9][10].

There are many SS techniques proposed by the researchers like Energy Detection (ED), cyclo-stationary feature extraction, matched filter detection, entropy detection [11]. These are all single-user SS techniques. ED, for its simplicity is the most widely used single-user SS technique. However single-user SS techniques are unreliable as they have some drawbacks like they cannot tackle multi-path fading, shadowing, and noise uncertainty issues. To overcome these drawbacks and provide reliability Cooperative Spectrum Sensing (CSS) is best suited [12].

CSS gives us enhanced sensing performance by observing in a spatially distributed environment. All the spatially distributed users give their observation or decision to reach a global decision. Decision of every user is very important at the Fusion Centre (FC) due to its location and environmental conditions.

At the FC a fusion scheme is applied on the received responses of SUs to determine the final decision on the presence of PU. Researchers have proposed many fusion schemes broadly divided in two categories: soft fusion rules and hard fusion rules [13][14]. These have some drawbacks of having more overheads and less accuracy respectively. So, an ANN based fusion scheme is used that overcomes both these drawbacks. Scaled conjugate gradient back proportion has been used as it has the capability to learn from previous datasets and is less computationally complex [15][16][17].

Related work:

Yang and Zhao 2015[18] proposed a technique where they predict idle channels on the basis of historical information. Then spectrum sensing is performed on these channels. Theoretically simulated results show improved throughput when compared with traditional method. When traffic intensity increases the

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throughput decreases. The proposed method outperforms the traditional method at varying traffic density and probability of wrong prediction for throughput. When the probability of wrong prediction increases the proposed method decreases gradually whereas the traditional method is unaffected. Ren et al. 2016[19] proposed dynamic channel access method for intra-cluster and inter-cluster to improve energy efficiency in CR sensor networks. For both type of clusters, the optimal channel selection is done at an early stage to avoid extensive channel sensing that conserves energy. But the packet loss is sometimes high. Costa and Ephremides 2016 [20] discussed performance trade-offs with respect to energy efficiency. A non-cooperative model cognitive wireless model was discussed for the trade-off between energy efficiency and throughput, and energy efficiency and spectrum sensing accuracy. The analysis show that to achieve some desired value of a parameters like throughput, the energy efficiency of SU will be reduced. They also proposed a cooperative network where the energy efficiency of cooperative is better than non-cooperative. In 2017 awasthi [21] et al. did a survey on various energy efficiency techniques available for CRNs. They claimed CSS improves detection probability in CRN. Sudhamani and satya sai in 2018 [22] considered optimising the number of SU in a CSS environment for maximum energy efficiency. OR and AND fusion rules were used at the fusion centre. The analysis showed better energy efficiency with OR rules even at lower detection threshold. In 2018 Shaghluf and Gulliver [23] performed experiments to show spectrum and energy efficiency under various scenarios of single spectrum prediction (SSP) and Cooperative spectrum prediction (CSP) with AND, OR and majority rules at the fusion centre. Further the performance of CSP is also evaluated using a hidden Markov model(HMM) and a multilayer perception (MLP) neural network. Results show that HMM gives better performance for CSP under majority rule, but the computational complexity is higher than MLP. Energy efficiency of SSP is better than CSP as increased number of SU increases overhead but in high traffic conditions CSP performed better. Jaglan 2109[17] et al. proposed a CSS technique using ANN to provide 98.5-98.7% sensing accuracy and 0.3-0.1% missed detection. This method is tested for its scalability as well so that any increase in number of users can be handled.

The above discussed techniques show the importance of energy efficiency in various networks like CR Sensor networks, CRAHNs, or CRNs. And CSS plays an important part in improving the sensing accuracy of a network to improve energy efficiency.

Methodology:

The analysis shows that delays cause a lot of energy consumption. All this energy is wastage of resources. Since there is a limited bandwidth and due to overloaded amount of data being transferred congestion occurs. In this paper we used frequency hoping to utilize surrounding frequency bands when they are free. To avoid any conflicts with primary users of that band we use a cooperative spectrum sensing technique that detects the presence of primary user in the channel. The accuracy of said technique is 98.2% with 0.3% miss detection.

AODV routing protocol uses a three-stage system for route selection; search stage, decision stage and acting stage.

In search stage: source node generates Route Request (RREQ) packets with destination node information and broadcast them to their neighboring nodes. Neighboring nodes further broadcast them to their neighbors. This process is repeated till the RREQ packet reaches the destination node as shown in figure 4.

In decision stage: the destination node generates the Route Reply (RREP) packet and sends it through the shortest path available as shown in figure 5.

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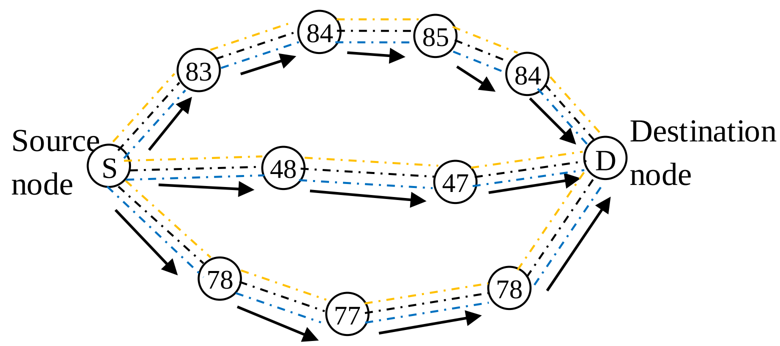

Fig 4. Searching of route from source till destination

→ RREQ Packet

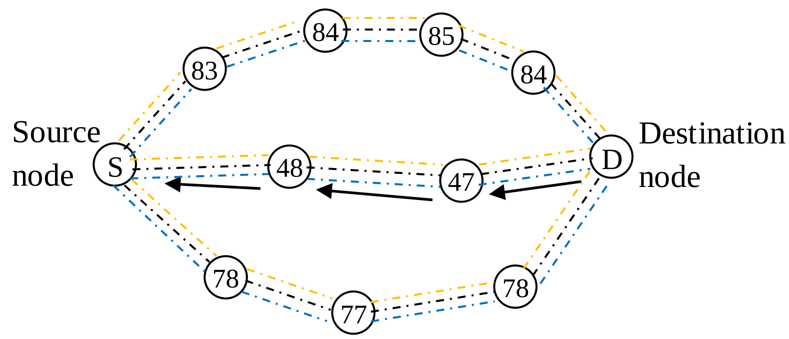

Fig 5. Reply for route decision from destination to source

← RREP Packet

In Acting stage: The data is transmitted over the selected route on the primary channel. Every node in the network uses ANN based cooperative spectrum sensing to identify any spare secondary frequency channel other than its own.

Every node has the ability to sense the presence of PU in secondary channels using energy detection. Energy of the sensed signal is calculated using equation (1). It is then compared against a predefined threshold λ to conclude a decision. The detector must choose one hypothesis from the decision statistics depending on the received signal. The threshold and the decision statistics are given in equation (2) and (3) respectively.

$$T(Y) = \frac{1}{N}\sum_{n=1}^{N}(Y[n])^2 \tag{1}$$

$$\lambda = \frac{\left[\frac{Q^{-1}(Pf)}{\sqrt{N}}+1\right]}{SNR} \tag{2}$$

$$Z = \begin{cases} T(Y) \le \lambda:\ H_0 \\ T(Y) > \lambda:\ H_1 \end{cases} \tag{3}$$

These individual decisions by SU's on received AWGN channel are sent to the fusion centre of transmitting node for a global decision about H_0 and H_1 indicating PU's presence. This global decision is achieved by an ANN based Cooperative spectrum sensing model as follows:

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1. Consider M SUs in a mobile ad hoc network.
2. Where k users participate in the decision-making process.
3. The received signal at FC by SUs be given as:

$$y_k = h_k m_k + n_k;\ k \in \{1,2 \ldots . M\} \tag{4}$$

Where $h_k = 1$ is the kth channel coefficient and n_k is AWGN noise. m_k is the PSK message signal,$m_k = 1$ indicates presence of PU and 0 indicates absence at kth SU.

4. Artificial Neural Network (ANN) is used at the FC to infer the global decision-making process for better performance even on a scalable network.
5. If $y_k > 0$, FC infer the presence of PU i.e $u_k = H_1$ otherwise H_0.

$$u_k = \begin{cases} 1;\ H_1 \\ 0;\ H_0 \end{cases} \tag{5}$$

Since the transmitter node now has the information of any empty frequency band around it. If the primary channel of transmitter node is busy then the data is hopped to the spare secondary frequency channel as shown in figure 6.

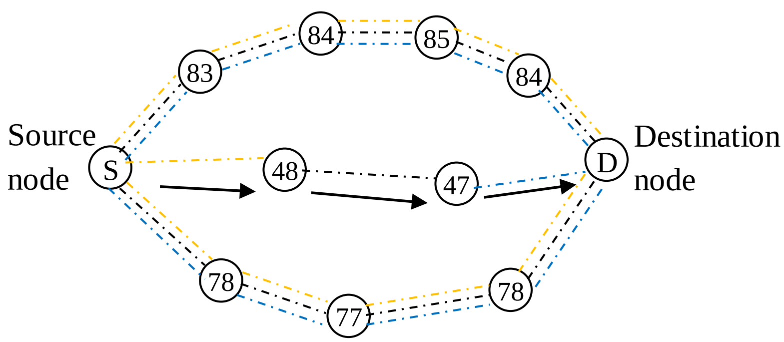

Fig 6. Data transmission on selected route

Results and Discussion:

After simulating the scenario with AODV and the technique discussed above the results have improved a lot. Energy consumption was the main concern in a densely deployed network. In a network where a lot of data is generated delays caused even more energy consumption which was uncalled for. Total network energy consumption per packet delivery has now reduced from ~9.3% to ~8.6%,average energy consumption for running route has also reduced from a ~2% to 1.2% as shown in figure 7 and 8 respectively. Since there is a drop in energy consumption the lifetime of a route has also increased. The first selected route delivered 15 packets for the proposed technique and just 11 packets for AODV protocol as this goes on to show that AODV attempted 117 packet deliveries in the network lifetime and the proposed technique attempted 127 deliveries as shown in figure 9. Since there are more packets delivered per route before a route dies the network size also stays high for the entire simulation and more nodes are available for route selection as shown in figure 10 and 11. This in turn improves the throughput as AODV provided ~93.1% throughput and the proposed technique shows an improvement and provides ~95.2% throughput. Energy consumed by hops is identical till the same route is running for AODV and proposed technique i.e. 6.3% but energy consumed by delays has been removed by the technique as shown in figure 12 and 13 respectively. So, the energy consumed by the running route that was ~10%for AODV as shown in figure 3 is ~6.3% for proposed technique. The occasional high peaks of energy consumption in proposed technique are the cases where no other frequency band was available for hoping either due to the presence of primary user or false detection.

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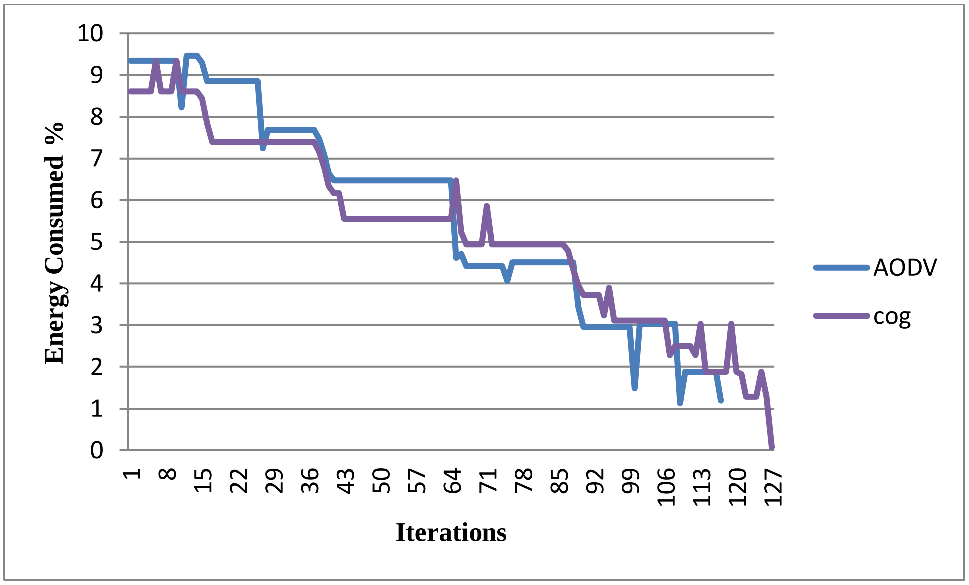

Fig. 7 Network energy consumption

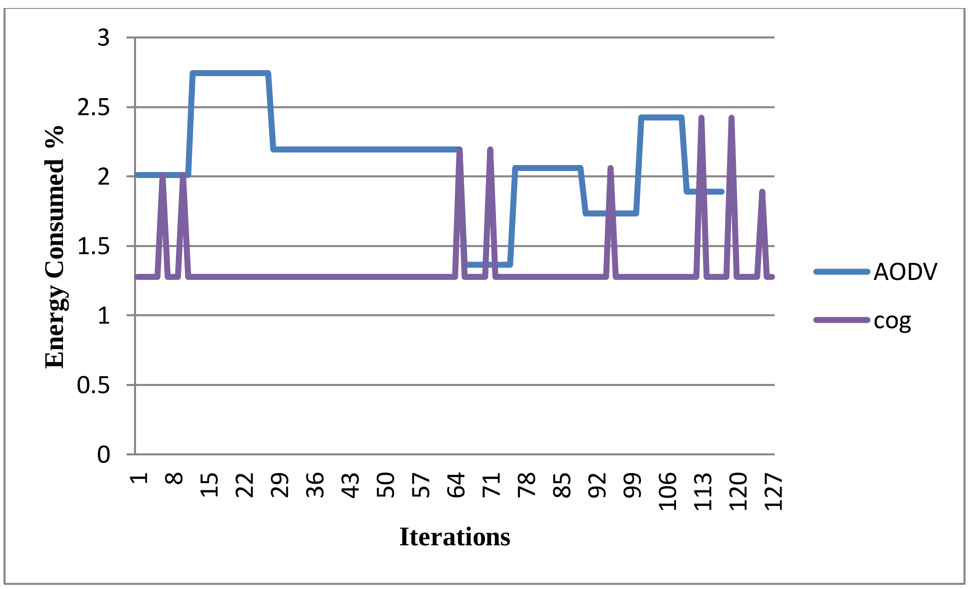

Fig. 8 Running route energy consumption

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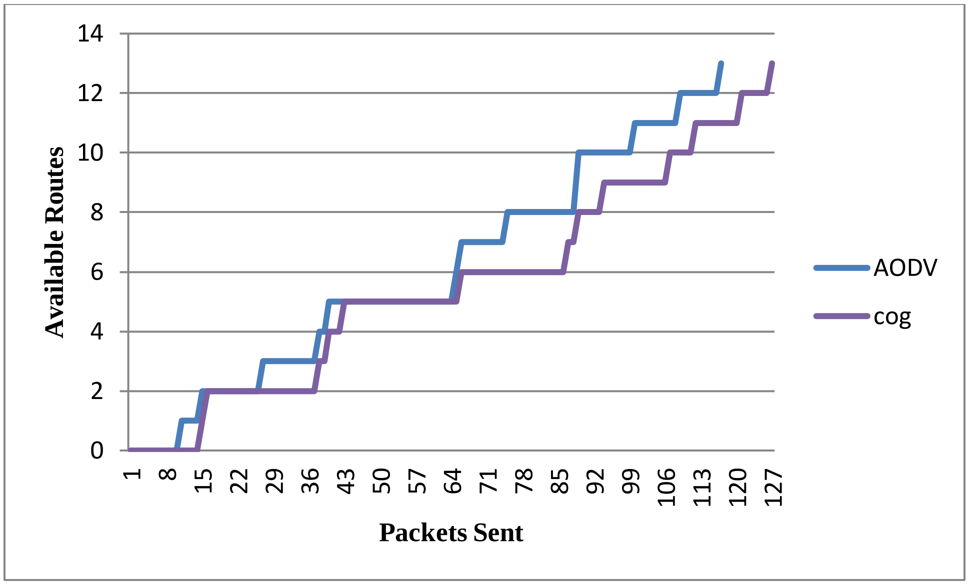

Fig. 9 Packets sent by source node

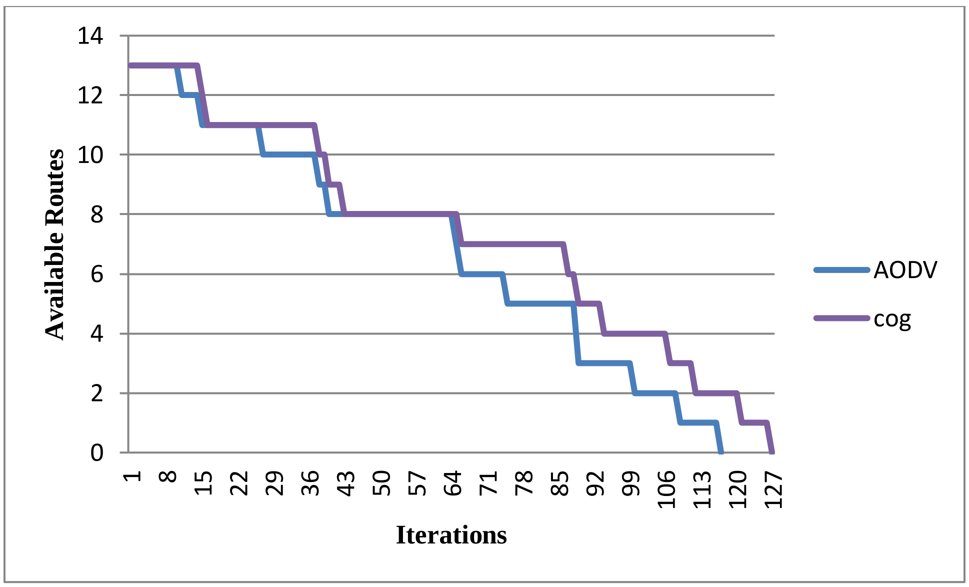

Fig. 10 Size of network w.r.t number of routes

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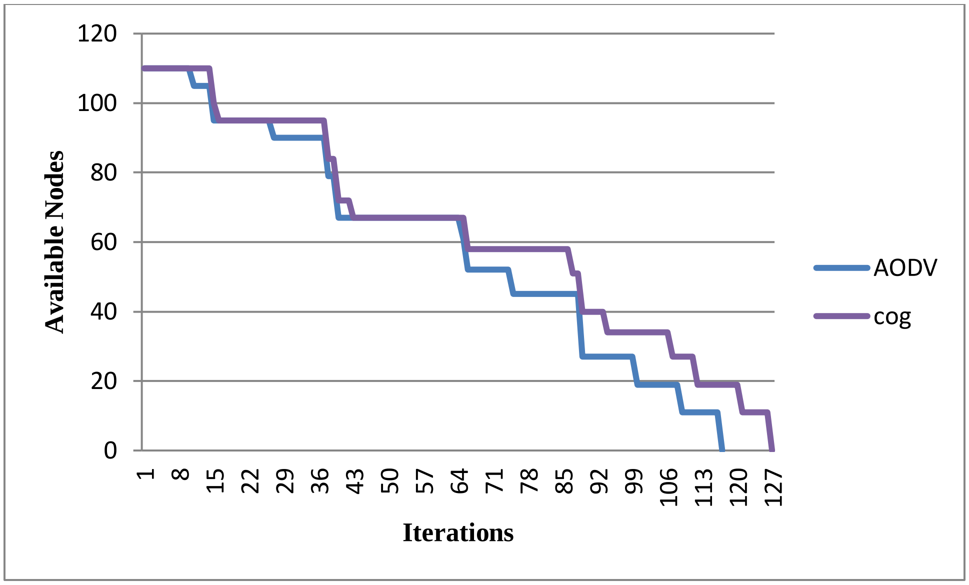

Fig. 11 Size of network w.r.t number of nodes

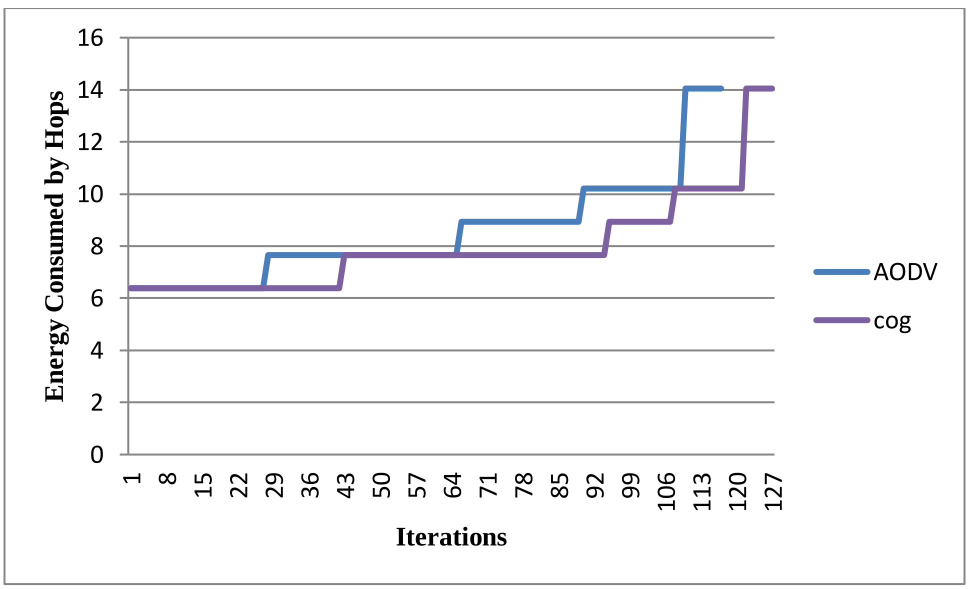

Fig. 12 Energy consumed by hops

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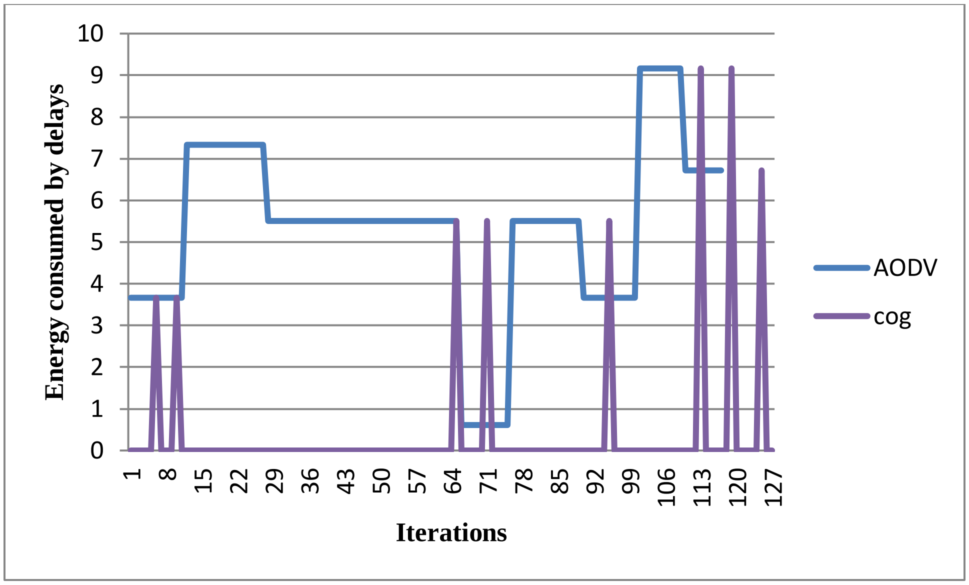

Fig. 13 Energy consumed by delays

Conclusion

The aim is to achieve maximum accuracy with no interference to PU. Cooperative spectrum sensing is used to achieve this aim. Local sensing decisions from neighboring nodes are combined at the fusion centre.Where an ANN based technique using Scaled conjugate gradient back proportion method is being used to inherit the global decision on the presence of PU. If the FC decides on absence of PU then the required node can send its data on the band of PU. This mitigates the time and energy consumed by the delays in a congested route. The high accuracy and negligible false detection rate make this approach best suited for Cognitive Radio Ad hoc Networks. Successful deployment of this technique ensures huge energy conservation. Since delay is almost removed from the routes. Route lifetime, network lifetime and throughput increased. For a running route ~40% of energy has been conserved by hopping the frequency to a free band and not waiting in queue.

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