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Cooperative Spectrum Sensing among Mobile Nodes in Cognitive Radio Distributed Network

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Abstract-**Recent advancements in communication have introduced several networking paradigms one of which is Cognitive Radio Network (CRN). CRN is a network of radios that can change its operating parameters based on interaction with the radio environment. Spectrum sensing for Cognitive Radio User (CRU) enables them to make use of unused spectrum portion. Consensus based algorithms are being developed by researchers to attain reliable spectrum sensing for which various techniques are employed. In this paper, the authors implement a consensus based algorithm by using energy detection as sensing technique and by utilizing cooperation among users. The consensus algorithm is applied on Mobile Nodes (MN) using random walk mobility model. Through this implementation an efficient cooperative spectrum sensing technique is proposed. Simulation results show that proposed technique has considerable lower missing detection probabilities and false alarm probabilities in distributed networks.**

Keywords: Cognitive radio network, Mobile Ad Hoc network, distributive network, energy detection, software defined radio, spectrum sensing

I. INTRODUCTION

Advancement in wireless communication requires efficient utilization of limited spectrum resources. Recent research shows that this limitation is because of spectrum management policies. The spectrum control is under the supervision of government agencies and is assigned to licensed holders for large geographical regions. Owning to this strategy the usage of assigned spectrum is from 15% to 85% of the total availability with a high variance in time as illustrated by Fig. 1 [1]. This leads to underutilization of a significant amount of spectrum. The cognitive radio, built on a Software-Defined Radio (SDR), is defined as smart wireless communication system that is able to sense the radio environment, learns from environment and adapt to statistical variations in the input stimuli, with two primary objectives that are reliable transmission and efficient utilization of spectrum [2-4]. Hence CRN are based on idea of exploiting the existing wireless network opportunistically. CRN has the ability of taking runtime decisions and transform its characteristics according to requirements of users and environment [5-6].

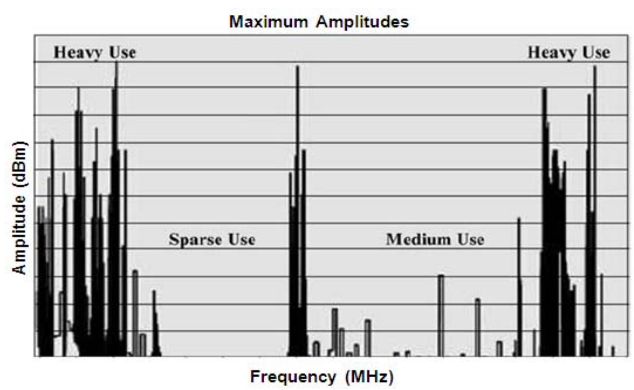

Figure 1. Spectrum Utilization [1].

Depending on network architecture, CRN can be classified as infrastructure based CRN and CR Ad Hoc Networks (CRAHNs) also shown in Fig. 2. Infrastructure based CRN has central entity such as base station for providing a backbone connection. While in CRAHNs the lack of central entity, the dynamic network topology, the distributed multi-hop architecture, and the location and time varying spectrum availability are some of the key distinguishing factors [7]. CRAHNs can be helpful in many important and critical situations. They can act as emergency networks in case of natural disaster, and as military network when primary network goes down [1].

In Mobile Ad Hoc Network (MANET) each device is free to move and can change links to other devices frequently. For this reason they are bit complicated as compared to infra-structure based CRN. Self-organization and correct spectrum sensing are major requirements of CR-MANET because CRU must be aware of its environment.

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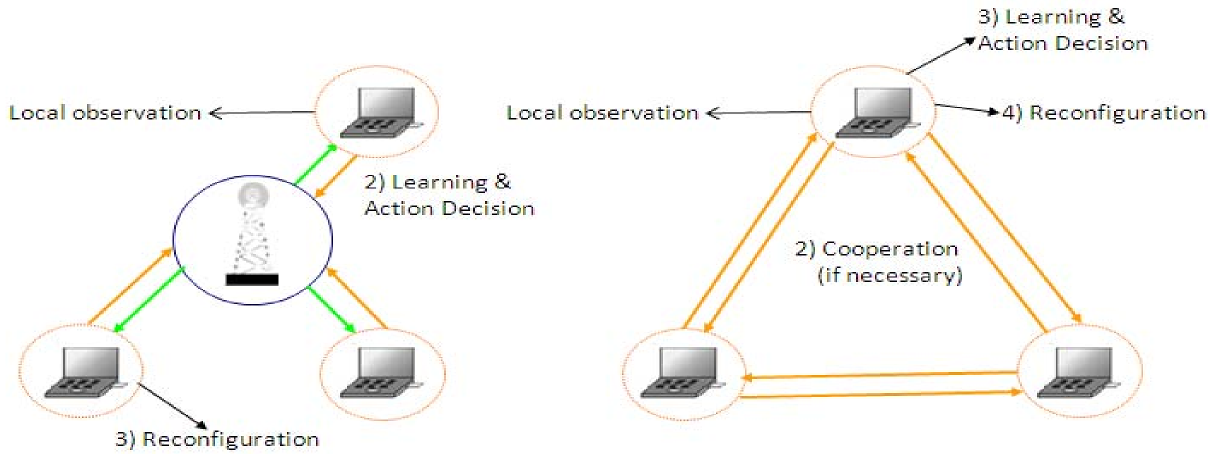

Figure 2. (a) Infrastructure based CRN (b) CRAHNs.

Major concern of CRU is that it should detect Primary User (PU) correctly so it may not disturb PU's transmission and detect spectrum holes efficiently [1], [7]. This means proficient spectrum sensing is core requirement for CRN. Current research related to spectrum sensing relies on improved local sensing and cooperative spectrum sensing for better results. In cooperative spectrum sensing each CRU shares its local observation with rest of CRUs in network which results in improved spectrum sensing.

Mobility models are used to define movement pattern of MNs. As in MANETs nodes are free to move so for this type of network it is important to track node movement. Two types of mobility models are: 1) traces, 2) synthetic models. Traces are observed in real life systems and provide accurate information while synthetic models represent the behaviors of MNs without the use of traces. New network environments require traces for ease in modeling. Frequently used mobility models in MANETs are random models in which nodes move in random direction and at random speed [8].

In this paper we present a cooperative spectrum sensing scheme for CR-MANETs. This scheme relies on interaction among CRUs/MN. CRU and MN are the terms used interchangeably many times in this paper. Each MN performs local sensing. Sensing is done using energy detection, so MN needs not to have prior knowledge of network topology. Results of local sensing are shared with other MNs in network. As nodes are mobile so mobility model used in this paper is random walk mobility model. In this model nodes move in random direction and at random speed. Simulation results are also included in this paper to show that consensus among MN in distributed CRN is achieved.

Rest of the paper is organized as follows. In Section II cooperative spectrum schemes and mobility models are discussed briefly. Section III involves methodology and Section IV describes proposed scheme. Section V includes simulation results and their description. Finally conclusions are presented in section VI.

II. RELATED WORK

The first phase of spectrum management is spectrum sensing which is divided into two branches that are local spectrum sensing and cooperative spectrum sensing. Local spectrum sensing techniques includes matched filter detection, energy detection and cyclo-stationary feature detection. Matched filter is linear optimal filter used for coherent signal detection to maximize Signal to Noise Ratio (SNR), but it needs prior knowledge of the primary system. Energy detection is optimal to detect the unknown signal if the noise power is known, it is simple to implement and does not have too much requirement on the position of primary users. Cyclo-stationary feature detection can detect signals with very low SNR, but it still entails some former knowledge of the primary user and is computationally complex [9], [10].

In [11] researchers discussed implementation issues in spectrum sensing and they found that cooperative sensing is a good solution because cooperative sensing very clearly reduce the probability of interference with PU and increase the probability of correct detection of PU. For cooperation they considered those nodes that were present from certain fractions of CRUs. They explored that by increasing the number of CRU in the network, probability of interference with PU can be decreased.

In [12] a Cognitive Radio approach for Virtual Unlicensed Spectrum (CORVUS) is proposed. In CORVUS, CRUs perform local sensing, these observations are then used for cooperation among CRUs to detect PU presence and channel allocation. In CORVUS a group of CRUs sense the spectrum pool. A pair of CRUs picks a set of sub-channels to from a CRU's link. For group management a Universal Control Channel

(UCC) exists which is used by all groups for coordination and separate Group Control Channels (GCC) work to exchange sensing information among CRUs and create CRU's links.

In [13] researchers have developed scheme for neighbor discovery in CRAHNs. The strategy they adopted is to make one node a leader and neighbor discovery operations are performed by this node. This leader also provides information about channels available for communication and also tells discovered nodes about their existing neighbors. So using this information network management can be easily done.

In [14] researchers have presented a biological inspired consensus-based spectrum sensing scheme. In this scheme there is no use of central entity and it is fully distributive. CRUs perform local sensing and send this information to their neighbors. After collecting information from neighbors each CRU makes use of biological inspired scheme to stimulate new state for consensus variable. This process continues to attain common value for all states. Researchers have also dealt with Spectrum Sensing Data Falsification (SSDF) attacks.

Among mobility models, mostly used by researchers are random models. Random models are further divided into several models but frequently used are "random walk" and "random waypoint". In random walk mobility model nodes move in a random direction and at random speed but each movement is made either at a constant time interval or at constant distance. At the end of each movement a new random direction and speed are selected from predefined ranges. Random waypoint mobility model is like random walk but here nodes pause between change in speed and direction. Node stays in a location for certain period of time which is pause time. Then it chooses random destination and travels towards it, stays in that location for certain time and in this way process continues [15].

Our proposed scheme like [14] is fully distributive. But in [14] consensus algorithm is applied on stationary nodes and our scheme applied same consensus algorithm on MNs and is adaptable for CR MANETs. Random walk mobility model is applied in our scheme. MNs make use of energy detection for local sensing so does not require prior knowledge about network topology.

III. METHODOLOGY

In our proposed scheme MNs randomly move for 50 steps in simulation area and use energy detection for local sensing because it is simple to implement and user need not to have prior knowledge of PU. Each MN performs local sensing. This observation is then shared with neighbors to perform cooperative spectrum sensing. Based on this cooperation final decision is made about presence or absence of PU. Neighbors with distance greater than 10m are not included for information sharing. The hypothesis model is given as follows

$$R(t) = \begin{cases} n(t) & H_0 \\ h * s(t) + n(t) & H_1 \end{cases} \quad (1)$$

where 'R(t)' is the signal received by MN, 'n(t)' is the Additive White Gaussian Noise (AWGN), 's(t)' is the PU signal and 'h' is the amplitude gain of PU signal. H_1 represents presence of PU while H_0 represents absence of PU. Local sensing of MN 'n' is represented as 'Y_n'. Flowchart for local sensing is shown in Fig. 3.

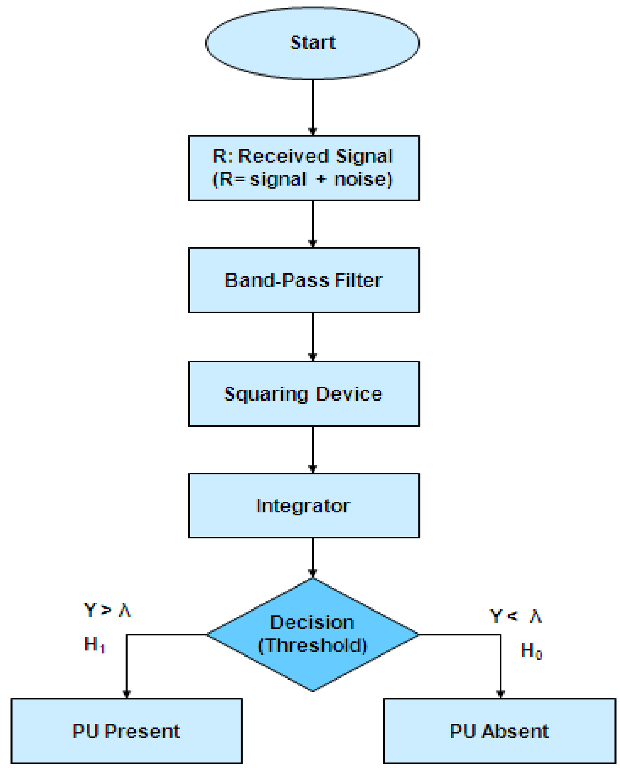

Figure 3. Flowchart for local spectrum sensing.

To compute power of received signal 'R(t)' it is passed to band-pass filter, the output of band-pass filter of bandwidth 'W' is squared and integrated over time interval 'T'. The output from the integrator is compared to λ and then local decision is made about presence or absence of PU. The output Y of the energy detection has the distribution [16]

$$Y = \begin{cases} \chi^2_{2P} & H_0 \\ \chi^2_{2P}(2\gamma) & H_1 \end{cases} \quad (2)$$

where χ^2_{2P} represent central chi-square distribution and $\chi^2_{2P}(2\gamma)$ represent non-central chi-square distribution. Each with *2P* (*P=TW*) degree of freedom and a non-centrality parameter of 2γ for the latter distribution.

Probability of detection P_d for each MN is calculated using generalized Marcum Q-function. This is given as

$$P(d) = Q(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (3)$$

where γ represents the SNR.

IV. CONSENSUS ALGORITHM

After local sensing each MN creates full duplex links with neighbors and share sensing information with them. The rule of neighbor discovery is that the neighbor with distance greater than 10m is excluded from neighbor list. So only the neighbors in the new list are used for state updating. Proposed scheme is an iterative process and continues until all the MN's energy information converges to a common value. Energy information at time instant k=0 for nth user is $x_n(0)$.The next state $x_n(k+1)$ of each MN is determined by cooperation with neighbors. After each iteration each MN's energy information is transmitted to its neighbors. This is the basic idea which is adapted from self-organization capability in CRAHNs. So this process continues until MN's energy information converged to common value represented by x*. The consensus based algorithm can be represented as [14]

$$x_n(k+1) = x_n(k) + \varepsilon \sum_{m \varepsilon N} (x_m(k) - x_n(k)) \quad (4)$$

where 'N' represents number of nodes, x_m is the neighbor with which x_n shares information. 'ε' is given as $0 < \varepsilon < \Delta^{-1}$ where Δ represents maximum degree of network. Flowchart for consensus among MNs is given in Fig. 4.

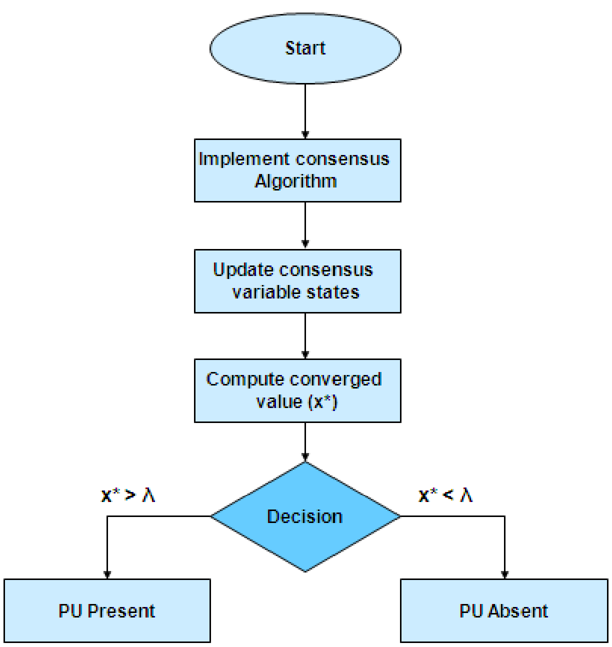

Figure 4. Flowchart for cooperative spectrum sensing.

The converged value is then compared with predefined λ and then decision is made accordingly.

$$Decision = \begin{cases} 1 & x^* > \lambda \\ 0 & x^* \le \lambda \end{cases} \quad (5)$$

So this proposed scheme does not require a common receiver such as base station. MN can communicate with each other and consensus based algorithm is employed to achieve higher and reliable spectrum sensing. Also because of energy detection no former knowledge of network topology is required.

V. SIMULATION RESULTS

In the simulations firstly each MN is allowed to move in 60m x 50m network area with transmission range of 10m. In each step MN covers a fixed distance of 1m. Trajectory of 10 nodes is shown in Fig. 5. As random walk mobility model is implemented so MN moves in random direction, performs sensing and receives a signal. Received signal can be combination of AWGN noise and PU signal or just noise. Using energy detection each MN detects the presence or absence of PU. For this purpose received signal is passed through energy detector, where after passing through band-pass filter of bandwidth W, a squaring device and an integrator, it is compared with predefined λ. The output of energy detector represented as Y is dependent on average SNR and time-bandwidth factor WT. In our simulation TW=5 and SNR=10dB. Initial value of energy vector is $x_n(0) = X_n$. During second step cooperative sensing is done. For this MN creates full duplex links with neighbors. In our simulation we considered network topology of 10 MNs. 10 MN establish a graph G = {N, E} where N represents number of nodes and E represents links. Links can go down if distance between nodes exceeds 10m. Random graph representation of network topology of 10 MNs is shown in Fig. 6.

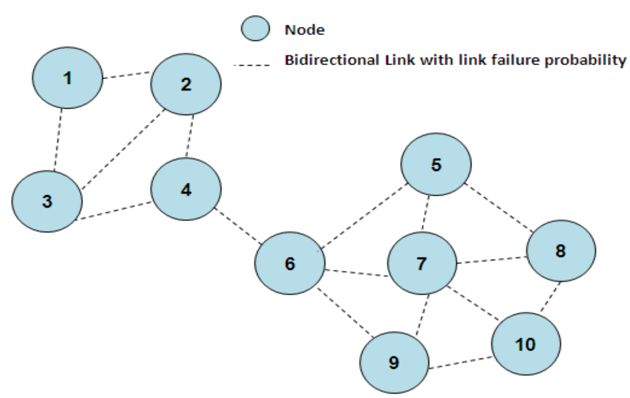

Figure 6. 10-node network.

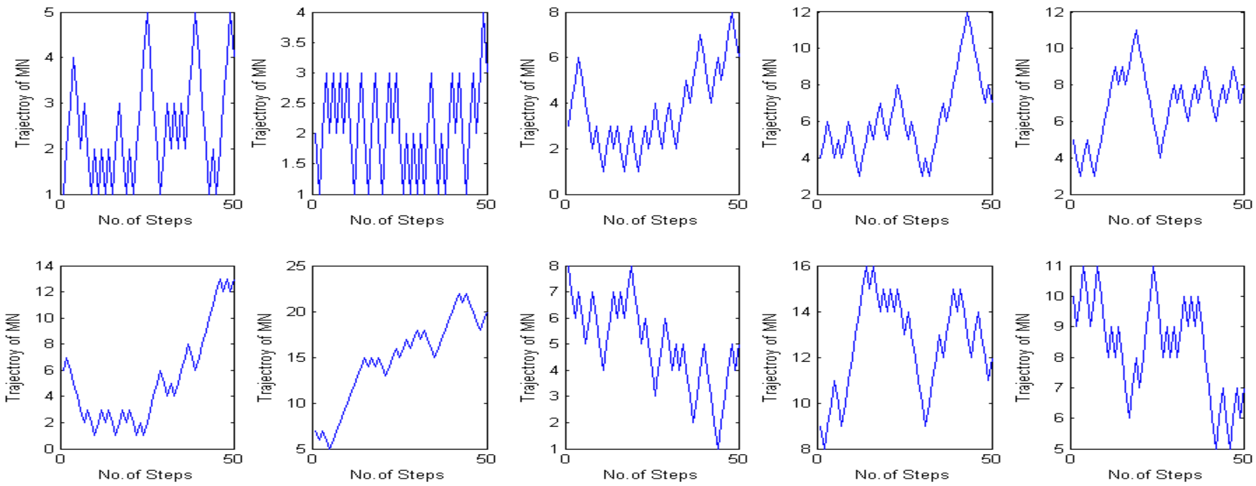

Figure 5. Random walk of 10 MNs

Proposed scheme is compared with existing OR rule scheme. In OR-rule cooperative sensing technique each CRU performs local sensing. Presence of PU is denoted by one ('1') and absence is denoted by zero ('0'). All of the local detections are sent to fusion center to sum all local detections. If summation is greater than '1' the PU is present else it is assumed to be absent [14].

Estimated energy of PU in network of 10 MN's in random graph is shown in Fig. 7. Initially the sensed energy for MNs varies greatly but consensus is achieved after some iterations. From Fig. 7 it is clear that after about 10 iterations difference between energy values is less than 1 dB which shows that consensus has been achieved. 'ε' effects the convergence rate of consensus algorithm. As value selected for 'ε' should be $0 < \varepsilon < \Delta^{-1}$, and in our case maximum neighbors of a node can be 5, $\Delta=5$, so $0 < \varepsilon < 0.2$.

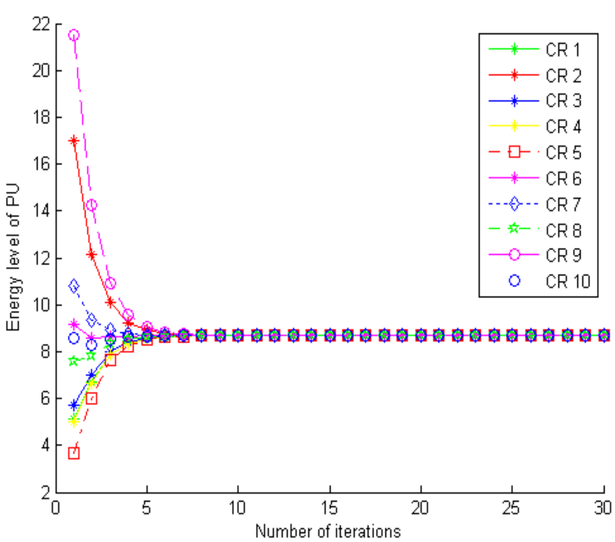

Figure 7. Convergence of network with 10 MNs.

Fig. 8 shows probability of detection vs. average SNR of MN. This is done to find out sensitivity in detecting presence of PU. In this case average SNR varies from -20dB to 20dB for all MN. Simulation result shows that proposed scheme has improved average SNR required for detection.

Next in simulation is relation between Probability of Missing detection (P_m) and Probability of False alarm (P_f). A high P_f will cause lower spectrum utilization. High Pm will result in higher missing probability of PU which in turns increases the chance of interference with PU. So this proposed scheme has better performance than existing OR scheme which is obvious from Fig. 9. So this shows that implemented consensus based algorithms decrease the P_f of PU.

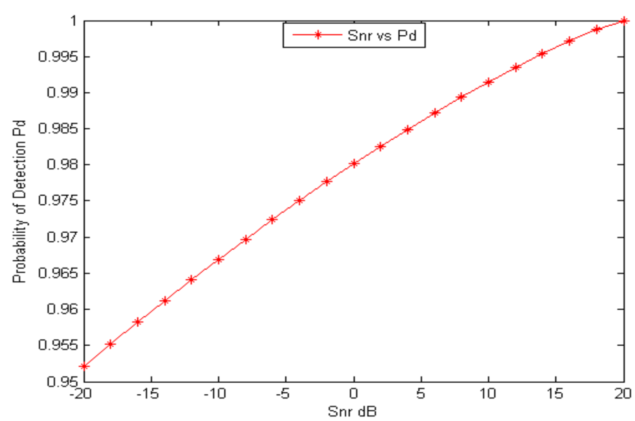

Figure 8. Detection Probability (P_d) vs. Average SNR.

VI. CONCLUSION

In this paper we have proposed a consensus based algorithm for cooperative spectrum sensing for MNs. For movement, MNs follow constraints specified by random

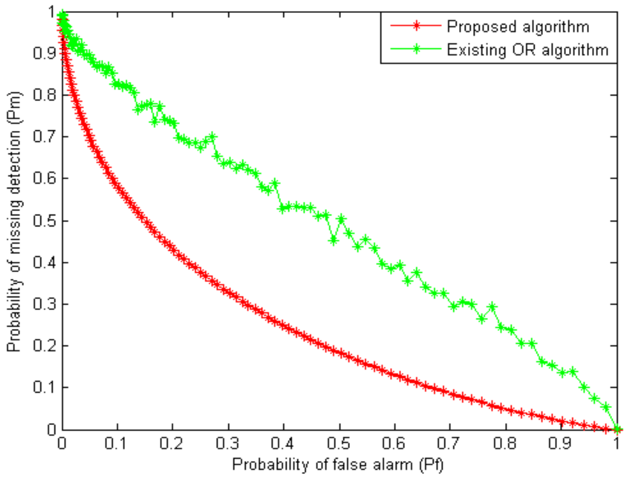

Figure 9. Missing detection probability (P_m) vs. false alarm probability (P_f) (Average SNR=10dB, TW=5).

walk mobility model. Energy detection is the technique adopted for transmission detection. In this scheme each MN performs local sensing and shares its sensing information with neighboring nodes. No central entity is involved for cooperation. Cooperation among MNs results in a single converged energy value. The converged value is compared with predefined λ and based on this comparison decision is made about presence or absence of PU. Simulation results show proficiency of proposed scheme.

One of the major advantages of this technique is that it is easy to implement and it does not require prior knowledge about network topology. Simulation results show that proposed scheme gives better results and is adaptable for CR-MANETs.

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