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Enhanced Bayesian Inference Model for Spectral Sharing using Network Coding in Cognitive Radio Networks

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Abstract

Spectrum sensing and data transmission over the unoccupied spectral band could be the communication with lesser transmission error while sensing and data transmission takes place at present time slot; however, efficient prediction of idle spectral band results in higher throughputs as sensing time can be allocated for transmission with some computational loads to secondary users. Distributed computation could be another technique to enhance the throughputs of the network so integration of wireless network coding for primary user (PU) data communication and Bayesian inference implemented to secondary users (SU) enhances the overall network throughputs. This research work evaluates the reduced miss detection and magnified idle probability of a particular spectral band because network coding integration to primary user data transmission reduces the number of transmissions over the network.

Keywords: *Inference, Bayesian Learning, Detection and Prediction, Network Coding, Scarce Spectrum, Spectral hole, Stochastic Prediction Model.*

1. Introduction

Continuous increased user data rate and area capacity demand can be addressed either moving communication radio channel to higher spectral band or efficient utility of the available spectrum. Research activities on shifting radio band to higher spectral band is followed by the development of mm-wave communication which is still in primitive phase and parallel efforts on efficient detection and utilization of radio spectrum available called cognitive radio technology has intensive research activities. Cognitive radio technology is intelligent and efficient use of radio spectrum either finding spectral hole or by allocating power to secondary users provided primary users experience interference below threshold to maintain rated quality of service (QoS). Because of dynamics of packet arrivals at PUs, intelligent and efficient spectrum sensing, and access are challenging task as described in [1]. For stochastic spectrum state, prediction of idleness of channels based on statistical information is also probabilistic

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projection. Additionally, quality of channel and corresponding probabilistic idleness is another factor to be considered while selecting channels. Sensing channel before data transmission is necessary to avoid interference; so reduced time for data transmission within the time slot. As a solution, prediction of channel availability could be done depending upon the prior channel state information.

Two of the major issues in cognitive radio are miss detection of spectral hole and delay in decision-making process because of stochastic channel state. Detection of spectral hole at present time slot is not enough for minimal interference to PU's data transmission but also prediction of the hole with higher accuracy for the next transmission slot is needed. This is because channels detected to be idle at current state could not be idle for next time slot or next state. Therefore, the prediction of channel state for next transmission time slot is probabilistic [2] and machine learning algorithms for the prediction are highly demanding and network coding could be one of the appropriate solutions for minimizing both miss detection probability or for the enhancement of prediction capability and delay in decision-making process.

Ahlswede et al. in [3], proposed seminal work on network coding, proved the theoretical achievability of upper bound by max-flow min-cut theory for a single source node to multiple sinks. Network coding fundamentally combines two or more information symbols to give functions with lower number of symbols which results in reduced bandwidth. Katti et al. in [4] were the first to study practical coding-aware wireless network coding, known as COPE, which incorporates opportunistic listening and learning neighbor states. Figure 1 gives a general scenario demonstrating how network coding minimizes the total number of transmissions in a network. Accordingly, encoded symbol x_e is simply XOR operation between symbols $x_{d,1}$ and $x_{d,2}$ as given by the relation below.

$$x_e = x_{d,1} \oplus x_{d,2} \tag{1}$$

From the function given in relation (1), it is obvious that x_e needs single channel rather than two channels for symbols $x_{d,1}$ and $x_{d,2}$ to be forwarded. So, network coded transmission of primary user data enhances the samples of spectrum available: enhanced detection capability, while reduced latency for network information or spectral information delivery to decision unit reduces the delay in decision making. For the prediction, better mathematical tool which studies the prior states and predict the next state is demanding and highly accurate prior information, of course; network coding integration to the transmission could enhance the miss detection and prediction capabilities of the cognitive techniques. So mathematical learning algorithms such as Markov chain model, Bayesian learning model can be used and in this particular work, Bayesian learning model is used.

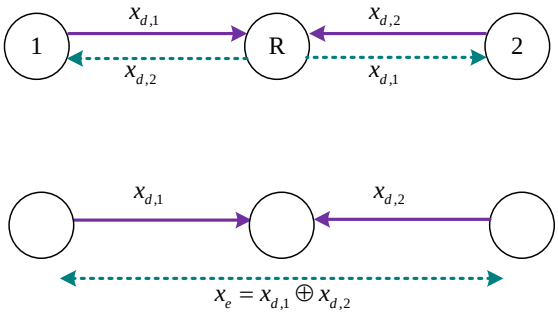


Figure 1. A general scenario illustrating the concept of network coding: a) without coding; b) with coding

Rest of the paper is organized as follow; section II presents literature review and section III include system model for the study. Within section IV, numerical analysis is demonstrated showing proposed methodology to be

better and the work is concluded in section V.

2. LITERATURE REVIEW

Network coding in cognitive radio network have been extensively researched in the last few decades and several cognitive radio networks paradigms provide reliable communications, efficient spectrum utilization, ensure data packets load balancing and improve QoS have been proposed by researchers. Li and Lv in [5] proposed network coding scheme for the better outage performance of both primary and secondary system in cognitive radio networks. In the study, they derived mathematical expression for outage probability of both primary and secondary system and both numerical and theoretical analysis validate the proposed relayed system which outperforms over conventional spectrum sharing scheme based on interference temperature (CSS-IT). The realization of the system exists only for cooperative relayed transmission to implement network coding process and performance of scheme depends on the correct decoding of the signals from PU to SU in first phase to implement network coding else conventional scheme (CSS-IT), was applied equivalently error free transmission in first phase. The authors in [6] proposed mathematical model to study adaptive network coding to underlay spectrum sharing system and evaluated end-to-end outage probability. The network coding implemented to secondary system was adaptive for the computational efficiency of the coding coefficients where coding coefficients were evaluated for number of subsets of nodes in the system. Outage probability was evaluated to be better compared to conventional network coding and so the reliable channel. The authors concluded that, their proposed scheme have been able to establish the minimum end-to-end outage probability with overall range of Signal-to-Noise Ratio, which in contrast the typical network coding scheme attained the optimal end-to-end outage probability only at high Signal-to-Noise Ratio. Li, Xiao, and Rasmussen in [7] proposed a secondary system to assist primary system in retransmission facilities with feeding back ACK to both the transmitters in primary and secondary system. Packets to be retransmitted were network coded at secondary transmitter with prior knowledge of decodability at receiver with feedback system and coding operation is simply XOR. Two coding schemes one with fixed coding size called stationary network coding and another with varying coding size as adaptive network coding were implemented and second scheme reduces the number of transmissions in retransmission session so enhanced network throughputs as demonstrated in their numerical analysis carried.

Zheng et al. [8] introduced relayed cooperative spectrum sensing information exchanged system to enhance the reliability. Efficient relay selection algorithm and network coding deployed at relay enhances the reliability of the spectral sensing information exchange and simulation results showed cooperative spectrum sensing based on network coding information exchanges system has better performance over cooperative spectrum sensing based on space-time coding information exchange system. Hao, Tang, and Xia in [9] studied network coding based distributed cooperative spectrum sensing in cognitive radio networks. Network coded transmission reduces the latency of the spectral occupancy information delivery among the SUs minimizing the decision-making time so the reduced sensing time and corresponding throughput of SUs. Increased sensing time lowers the probability of false alarm; however, higher time consumption for decision making decreases the throughputs. In the study, authors modeled detection problem as binary hypothesis testing problem and theoretical analysis has been carried. Both the theoretical and numerical analysis shows network coding based distributed cooperative spectral sensing scheme had better performance over scheme without network coding and non-cooperative schemes in terms of throughputs and probability of detection of channel occupancy by PUs.

Mu et al. [10] proposed stochastic model for SUs throughput and probability of confliction, interference probability being emergence of PUs and SUs transmission time are random and network coding reduces the transmission time. Numerical analysis demonstrated validates their proposition that network coding enhances the

efficiency of spectrum utilization in cognitive radio networks over traditional ARQ system. From the numerical analysis, it has been observed that SUs throughput is higher compared to ARQ and decreases with increased channel erasure probability. Similarly, lesser confliction probability compared to conventional ARQ and increased confliction probability with channel erasure probability as transmission time increases so increased transmission time for PUs while confliction probability increases with increased arrival rate of PUs due to increased transmission time for PUs. Wang et al. [11] have been focusing on the efficient network coding scheme for PUs to increase spectrum predictability in a cognitive radio network, they proposed method has improved the spectrum available for the SUs. In this study, each PUs has been applied in random linear network coding and spectrum shaping framework before sending data packets to the destination according to the randomly arrived packets. The SUs performs adaptive channel sensing in two-stage, firstly sensed the PUs idle channel slots and secondly offer priorities to PUs for idle channel spectrum. Overall, prediction and spectrum sensing strategies of the PUs and SUs generates free spectrum space for SUs data transmissions and increasing throughput under random traffic.

Meanwhile, the authors in [6, 12] have investigated the opportunistic systematic network coding scheme for SUs while contemplating the uncertain idle slot of PUs factors to establish systematic network coding (SNC). To find the uncertainty of the PUs idle slots, a confidential interval estimation is employed to estimate the expectations of idle duration on average for stochastics idle slots and multi-armed bandits, this technique is employed to sequentially determine the idle slots for a non-stochastic case, respectively. Then, a coding parameter selection algorithm is employed for systematic network coding which determine the complicated correlation among the reception at different receivers. Moreover, a block size selection of algorithms for systematic network coding is employed which adaptively estimate and maximize the proportional of the coded and uncoded packets under a given idle slot. Qu et al. [13] studied network coding-based multicast in multi-hop CRNs considering uncertainty in spectral availability. Originally authors formulated chance-constraint problem which was transformed into tractable optimization problem which is convex problem using Bernstain approximation. The problem was further decomposed into subproblems using Lagrangian relaxation to find the stable sets of two-dimensional conflict graphs and distributed algorithm was implemented and simulation results show the distributed algorithm outperforms over conventional multi-hop CRNs without network coding. Authors in [14] tried to address some of major issues in CRNs such as delay in decision making and detection capability to be enhanced. For the minimization of detection delay time either CUSUM algorithm was employed if PU's spectral dynamics is unknown or viterbi algorithm if PU's spectral dynamics are known. Authors deployed network coding as batch processing which not only maximize the throughput but also improves the correlation pattern of PU's spectrum to track channel states and additionally Partially Observable Markov Decision Process was implemented for better tracking of PU's spectral states so maximized throughput. The results analysis with actual radio measurements using cognitive radio testbed of Intelligent Automation Inc., network coding benefit was observed in both detection capability and network throughput. Lu et al. [1] presented overview of RF energy harvesting and challenges in dynamic spectrum access. Authors formulated optimization problem based on Markov decision process for optimal selection of channels that maximize the SU's throughputs. Though dynamics of spectrum itself is challenge for channel selection, energy harvesting adds additional challenges for optimal channel selection. Jacob, Jose, and Mathew [15] proposed hybrid model for prediction of occupied spectrum where Bayesian inference was integrated to exponential weighted moving average (EWMA) based prediction model. Bayesian inference model they have studied was found to be computationally efficient with better inference for data distribution of different α and β values while their hybrid model had comparatively good performance than EWMA prediction approach.

3. SYSTEM MODEL

If there is any technique to increase the number of idle blocks or idle time slots equivalently, that could be network coded transmission for licensed user data over the channel. Network coding process helps to increase the number of idle slots or blocks and so the probability of idle slot to the next frame or in future.

3.1Uniformly Distributed busy-idle channel

Given spectral band was partitioned into resource blocks and observation of frame or resource block's occupancy was carried for random data transmission over the radio. Depending upon traffic distributions, resource blocks were assigned indicating busy or idle state and the supervision or spectral sensing gives the distribution X which is idle distribution. The observation data is array of '1' and '0' indicating '1' for busy and '0' for free slots.

Bayesian machine learning algorithm was used for the prediction of spectrum hole for next time slots. Further enhancement to the prediction model was prompted by deploying network coded transmission of PU's data transmission. There are lots of random variables to be considered to infer the occupancy of a particular spectral band. If θ is modeled as number of successive frames for particular resource block to be idle and X distribution of the band state, using Baye's theory, posterior distribution for idle time, θ for give X can be infer with prior knowledge of θ as follow:

$$P_r(\theta \mid X) = \frac{P_r(X \mid \theta) P_r(\theta)}{P_r(X)} \tag{2}$$

These kinds of learning methods are highly demanding once the static frequency planning approach is flipped to resource block assignment concept and selection of orthogonal channels in terms of time, space and frequency is challenging task within available spectrum.

When network coding was implemented to primary user transmission, for simplicity combination of two symbols gives single symbol to be transmitted, one of the channels could be unoccupied which results increase in number of idle channels. Additionally, lots of channels could be free, available for secondary user access, when to larger number of transmissions are network coding applicable. For this reduced usage of radio band, it can be infer that there are both increased detection and prediction probability; Bayesian inference model as shown in equation (2) after network coding process was implemented to primary user data for wireless transmission was used to predict the idleness of the band to next transmission time.

3.2 Alpha Beta Distribution for busy channel

For the unknown stochastic distribution, probabilistic distribution can be modeled using α and β parameters. Only if θ belongs to gamma distribution can $P_r(\theta)$ be estimated from $gamma(\alpha, \beta)$ function as $P_r(\theta) \propto \theta^{\alpha-1} e^{-\beta\theta}, \theta > 0$ where α defines the shape of gamma function and $\beta = 1/\alpha$ the rate of channel being occupied. If the distribution $P_r(X)$ is fixed, the posterior distribution, $P_r(\theta|X) \propto P_r(X|\theta)\, P_r(\theta) = \theta^{\alpha} e^{-\theta(X+\beta)}$. Hence the posterior distribution $P_r(\theta|X)$ is also gamma distribution.

For this distribution, network coding deployment to PU's data transmission produces some of the data X to zero, channel unoccupied, so the evaluation of $\theta^{\alpha} e^{-\theta(X+\beta)}$ gives increased posterior distribution $P_r(\theta|X)$ as exponent $(X + \beta)$ decreases. Selection of parameter values for α, β and coding probability is crucial because distribution shape is not well defined; coding probability is another parameter with unknown distribution shape.

3.3 Channel utilization of SU based on the Contention window size

The contention window (CW) is the most crucial factor to periodically and dynamically control the medium access radio channel of the SUs. The objectives of the CW back off algorithm is to achieve maximum throughput, minimize delay, and low collision rate, under idle channel condition [16]. When the channel condition is idle, the backoff time decreasing exponentially. On the other hand, when the channel is in a busy condition, the backoff time will stop decaying till the channel condition becomes idle. The data packets transmission starts when the backoff time end and it can be calculated as follows:

$$T_{backoff} = CW \times T_{slot} \tag{3}$$

here T_{slot} refers as the single time slot length which is estimated with the physical layer, CW is varies between 1 and CW, i.e. $CW_{\min} \le CW \le CW_{\max}$. At the point when the packets collision occurs between the SUs, every user doubles its backoff time until the $CW_{\max}$. Once the data packets are successfully delivered to the destination, the backoff time minimized to $CW_{\min}$. The CW size is estimated based on the data packets delivered as bellows:

$$\begin{aligned} &CW \leftarrow \min\ (CW \times 2, CW_{\max}) \text{ when there exists collision,} \\ &CW \leftarrow CW_{\min} \text{ when the data are sent successfully} \end{aligned} \tag{4}$$

here the CW defined as the backoff time i.e. $CW_{\max} = 1024$ and $CW_{\min} = 2$. The proposed study uses a fixed CW in each round. If the data packets collision is determined, the CW size is does not become doubled. The SUs estimates the data packets delivered probability with different time duration with constant CW size till the all packets successfully delivered to the destination. The new CW size can be estimated as follows:

$$\begin{aligned} &CW \leftarrow \max(P_n) \quad \text{when there exists collision,} \\ &CW \leftarrow CW_{\min} \quad \text{when the data are sent successfully} \end{aligned} \tag{5}$$

here P_n defined as the selection probability of the CW size. If the data packets collision occurs, the SUs selects the highest probability of CW size from the constant CW. When the data packets are delivered successfully, the size of CW will be going toward the $CW_{\min}$. The CW size selection probability using the sift protocol [17] is estimated as follows:

$$P_n = \frac{(1-\omega)\psi^{CW}}{1-\omega^{CW}}\omega^{-r}, \qquad \text{n} = 1, \ldots\ldots, CW \tag{6}$$

where CW∈ 1, $CW_{\max}$, n refers as the distribution parameter varies between 0 and 1.

$$\psi = N_1^{-(1/(CW-1))}, \tag{7}$$

here N_1 refers as the number of SUs using first idle channel slot. The ψ value is depending upon the number of SUs participant in the first idle channel slot. Based on the above equation (6) the SUs selects time slot for sending data packets through the idle channel that lead to minimize the collision among the SU and reduce the time of data transmission

4. NUMERICAL ANALYSIS

Though the prior information of idle slots or resource block could not be highly accurate in practice, for our study, prior information of idle slots is assumed to be accurate. It can also be implied probabilistic approach for the prediction of a particular slot to be idle providing minimal interference to other licensed users. As prior information, number of resource block idle in a frame and in successive frames was studied and data were statistically evaluated for probabilistic study and prediction for continuous idleness to the next frame.

From the fig. 2, numerical analysis carried for Bayesian inference model and network coding integration, it can be observed that network coding magnifies the idle probability for the next time slot and for larger window size, more or less steady value of idle probability; that is converged statistics. Probability of idleness is higher for only maximum of 20 primary users were active and 30 resource blocks out of 50 per unit time slot were unoccupied. Increase in primary users definitely reduces the probability of idle blocks in next time slot.

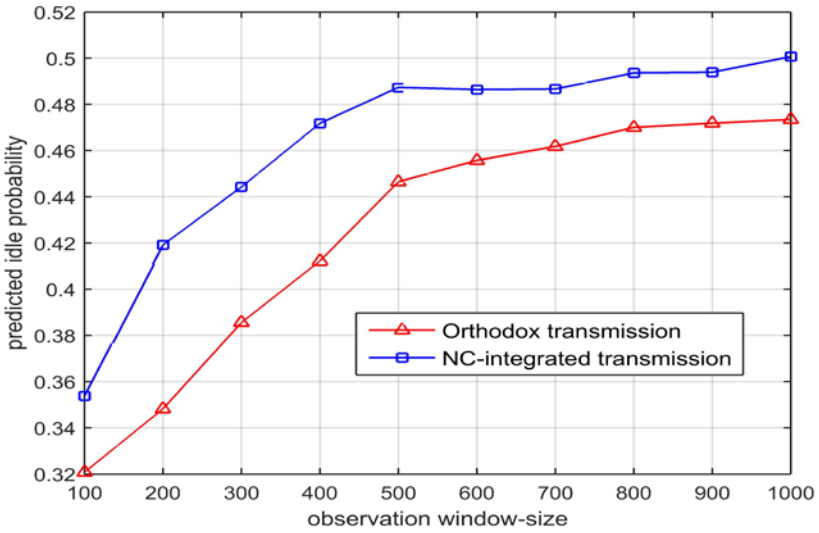
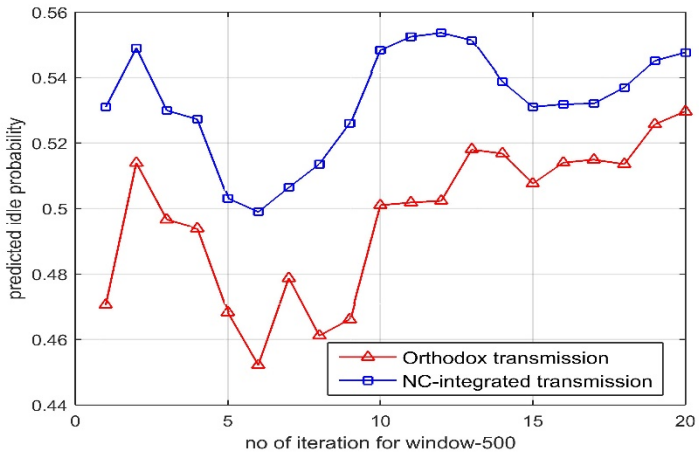


Fig 2. Network coding integrated Bayesian Inference model

Fig.3 presents the inference for the next time slot with fixed sample size of 500. Small fluctuation in the prediction is because of stochastic nature of channel without following any known distributions. However, increased prediction probability of idle band for next time slot is for implementation network coding prompts idle spectrum at present. For sample size of 500 samples, probability values were found to be fluctuated within range of 0.08; even smaller fluctuation could be expected for higher sample size. Fig. 2 demonstrates smaller variation in



prediction probability for sample size of higher than 500 samples.

Fig 3. Network coding integrated Bayesian Inference model for fixed window-size

There is no cooperation between licensed and unlicensed users; unlicensed users, however, get channel state information from relays through which licensed users communicate. Hence, the system model could not be assumed cooperative communication, there could be cooperation between primary users to ensure network coding, even though.

5. CONCLUSION

Bayesian inference is computationally efficient for idle channel detection model and integration of network coding to the wireless transmission prompts free channels available due to reduced number of transmissions. Bayesian mathematical model with its numerical analysis demonstrated shows the integration of network coding for radio transmission makes model better in idle channel inference. Hence network coding enhances the detection probability of idle spectrum in radio transmission. Probabilistic study converged within a range of values when sample size is very large and steady values are expected for that sample-size. From the numerical analysis, for sample size of more than 500, idle probability is within very small perturbation. Under higher computational cost for processing of larger number of data has Bayesian prediction model higher accuracy.

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