Packet Size Optimization for Topology Aware Cognitive Radio Sensor Networks

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***Abstract*—In this paper, we propose a framework to optimize the packet length and modulation level to determine the optimal packet size (OPS) for topology aware cognitive radio sensor networks (CRSNs) using a variable rate modulation scheme. A generalized network topology with specific node density of the Primary Users (PUs) is accounted to estimate the OPS. Based on stochastic geometry and non-linear optimization techniques, a joint multivariate optimization problem is formulated to determine the OPS for the topology dependent CRSNs.**

I. Introduction

In conventional Internet of Things (IoT) sensor networks the digital data packets contain the information bits along with the redundant header and trailer bits. Under the influence of a large number of users from the surroundings, the chances of collision become much higher, resulting in the increase of retransmission overheads and energy costs. Smaller packet size increases the overhead due to frequent transmission of redundant header and trailer bits. This is unsuitable for delay sensitive applications. Therefore there exists a tradeoff between the overall energy consumption of the cognitive nodes and overall end-to-end delay, which must be considered to estimate an optimal packet length for transmission [1]. The same holds true in case of CRSNs where CR features like the overhead costs due to channel sensing and channel-handoff, leveraging the *a priori* information about the non-cognitive users must be included in the optimization formulation. Majority of the literature available towards the determination of OPS for CRSNs like [2], [3], leverages on the *a priori* information about the average busy and idle duration of the non-cognitive user based on the duration of their traffic generation. This *a priori* information could be obtained using different techniques like sensing of the beacon signals, geolocation databases and spectrum sensing [4]. Furthermore, there are only handful of literature available like [5], where the *a priori* information like node density and spatial distribution of the non-cognitive users are used alongside the occupancy information. This additional information about the spatial distribution of the non-cognitive nodes provides higher degree of freedom to the cognitive users to adapt their transmission parameters and cognitive resources in a more efficient way. However, there is no work available, to best of our knowledge, where this valuable information about the spatial information is utilized towards OPS determination. To this end, this work proposes a joint optimization problem is formulated to determine the OPS for topology aware CRSNs.

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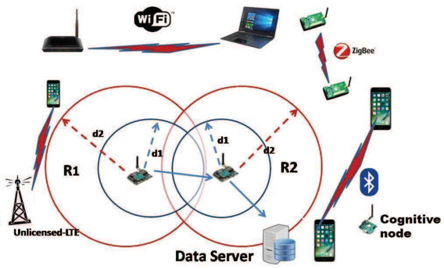

Fig. 1. Basic system architecture of topology aware CRSN

II. System Model

A topology aware CRSN is shown in Fig. 1. There are two sensor nodes equipped with cognitive features of channel sensing and hand-off denoted as cognitive nodes. It is assumed that any one of these cognitive nodes requires to transmit its data to a remote data gathering server in a multihop manner through an intermediate cognitive node. In Fig. 1, only a single cognitive node pair is shown but for a general network topology there can be M such pairs involved in data transmission. These cognitive sensor nodes coexists along with other communication standards sharing unlicensed ISM band like WiFi, Zigbee, Bluetooth, LoRa and Unlicensed LTE. These M cognitive nodes are assumed to share C number of ISM channels. A distributed time slotted channel access scheme is selected. The probability that no non-cognitive users lie within the range of the two cognitive nodes involved in data communication can be estimated using the concept of stochastic geometry. It is equivalent to no non-cognitive users present within the area of $R_1 \cup R_2$ denoted as $S(d_1, d_2)$ which is a function of d_1 and d_2 where d_1 and d_2 are range of the cognitive and the non-cognitive users. The probability of such an event occurring will depend on the estimated value of $R_1 \cup R_2$ and node density of the non-cognitive users λ_{NC}.

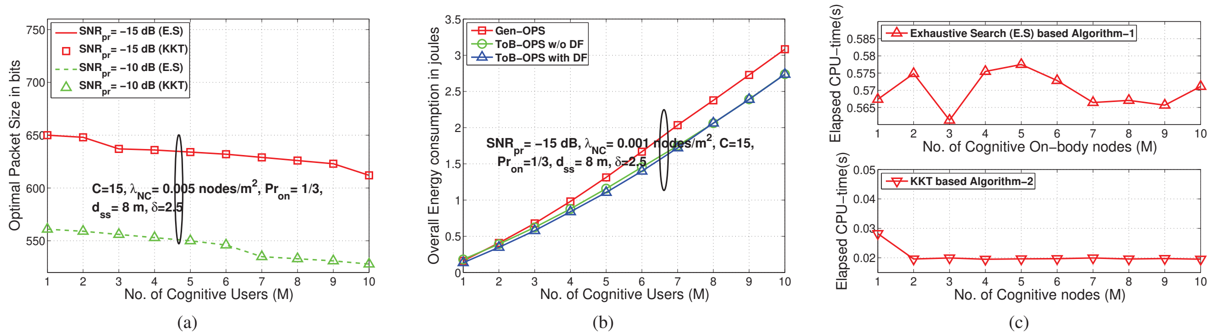

Fig. 2. a. OPS vs No. of Cognitive Users using Exhaustive Search and KKT based algorithms at different SNR_{pr} for ToB-OPS with DF b. Overall energy consumption vs Cognitive users for Gen-OPS, ToB-OPS without decision fusion (DF) and with DF at SNR_{pr}= -15 dB c. Complexity analysis in terms of elapsed CPU time for E.S based Algorithm and KKT Based Algorithm for ToB-OPS with DF.

III. Optimization Problem Formulation

The cost function is designed in a way such that it could capture the effects of the involved decision variables (packet size, modulation level and node density of non-cognitive users) on the energy-efficiency and reliability. Therefore, it is formulated as a multiplicative factor of the energy efficiency and reliability. Furthermore, few of the practical constraints like transmit power constraint, average error probability, detection and false alarm probabilities threshold are also considered because of the CR mode of transmission. The non-linear multivariate fractional optimization problem thus formulated is NP hard by nature. Therefore, two algorithms based on Exhaustive Search and Numerical bisection assisted Karush-Kuhn-Tucker (KKT) solution techniques are proposed to solve the optimization problem.

- Exhaustive Search (ES) Algorithm: Set of discrete values of the packet size $l_s = \{100, 101...1000\}$ and modulation level $b = \{2, 3, ...9\}$ are considered for a given non-cognitive user density λ_{NC}. The feasible region of l_s is determined for a given b that satisfies the transmit power constraint. The maximum value of cost function η_{topo} is estimated and its corresponding optimal value l_s^*. Similar estimation is carried out $\forall$ b. The b that provides minimum value of η_{topo} provides the optimal modulation level and the corresponding l_s^* is the OPS.
- KKT based Algorithm: l_s is considered to be as continuous. $\eta_{topo}^{'}$ is estimated and solved for its root l_s^*. Rest follows the steps E.S Algorithm.

IV. Numerical Results

In Fig. 2(a), it is observed that the results obtained using both the algorithms shows a perfect match in terms of its output establishing the accuracy of our simulation results. Moreover, the OPS value decreases as M increases. This is because with an increasing number of cognitive users in the system, the energy consumption per bit required to attain the specified BER threshold becomes larger. Thus, the value of the objective function (η) increases because η increases with k_1 for a fixed b and l_s. With increasing value of M, η increases because it is an increasing function of the energy consumption per bit (k_1). When the objective function η is compared for different packet size l_s within the search range of 100 to 1000 bits for a given value of M, it shows a concave behaviour with an unique maximum at l_s^* and as such the value of the optimal l_s denoted as l_s^* at which η is maximized decreases with k_1. The higher and lower values of k_1 corresponds to higher and lower number of cognitive users M in the system. Similarly, as SNR_{pr} increases from -15 dB to -10 dB, the OPS decreases. At M= 4, the OPS value at SNR_{pr}= -15 is 630 bits, while at SNR_{pr}= -10 dB it's around 551 bits.

Fig. 2(b), plots the overall energy consumption of the system against the number of cognitive users for the generalized OPS (Gen-OPS), Topology based OPS without decision fusion (ToB-OPS w/o DF) and topology based OPS with decision fusion (ToB-OPS with DF) at SNR_{pr}= -15 dB when there are 10 non-cognitive nodes within a $(100m \times 100m)$ area. It is clear that the topology based OPS with decision fusion provides the minimum overall energy consumption as compared to Gen-OPS and ToB-OPS without DF in-spite of the fact that additional channel sensing energy is consumed at both the cognitive transmitter and receiver.

In Fig. 2(c),the time complexity analysis of ToB-OPS with DF strategy is shown. Montecarlo simulation is carried outfor over 5000 iterations to estimate the average time elapsed time to execute the required to exhaustive search and KKT based. KKT based algorithm outperforms the E.S by a significant margin where it is seen that the CPU takes nearly 20 ms to execute KKT based algorithm while for E.S it is much higher. It can be proven that Algorithm-1 is of sublinear order of complexity.

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