Network Coding Challenges in Cognitive Radio Network

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ABSTRACT
Network coding is a method that can enhance the network throughput by reducing the amount of work overload in the network while still ensuring that all user data is transferred. With network coding, a node can improve its transmission efficiency by combining several packets together and sending only the resultant encoded packet if the coding conditions are satisfied. Network coding has been successfully applied in Cognitive radio network (CRN).It exploits the utilization of unused spectrum or white spaces, effectively and efficiently. In CRNs, network coding schemes are also applied to maximize the spectrum utilization, as well as to maintain the effective and secure transmission of data packets over the network. In this paper, we provide a comprehensive survey of NC schemes as well as the applications of network coding in CRNs. Finally, we present open issues, challenges, and future research directions related with network coding in cognitive radio networks.

Index Terms—Cognitive Radio Network (CRN), Network Coding (NC), Dynamic Network Coding (DNC), Forward Error Correction (FEC), Layer Network Coding (LNC)

1 INTRODUCTION

Firstly coined by Mitola in 1999 [1], cognitive radio (CR) is a promising technology for solving the problem of the coexistence of spectrum scarcity for new applications and low usage ratio of the allocated spectrum in wireless communication [2]. Based on the latest development of software-defined radio technologies, CR enabled users (CRs) can dynamically sense the network environment, find idle spectrum, and reconfigure operation parameters to access the temporally unused spectrum opportunistically without insufferable interference to licensed users (also referred as primary users, PUs). This flexibility enables CR networks to increase spectrum efficiency and accommodate to various application requirements through self-organization and dynamic reconfiguration. The end-to-end performance is challenged by the distributed multi-hop architecture, dynamic network topology, diverse quality of service (QoS) requirements and time and location varying spectrum availability [4], necessitating extensive research before large scale deployment of CRAHNw [3].
As the interference to PUs is strictly restricted, CRs should vacate the spectrum on detecting the presence of PUs. Spectrum availability in CRAHNs is determined by the spatial distribution and spectrum usage of PUs, resulting in dynamic spectrum heterogeneity across the network. This dynamic and unreliable spectrum environment proposes special challenges for efficient utilization of idle spectrum in multi-hop collaboration. For media access control, messages with information for resource reservation and competition need to be exchanged among CRs. Yet the dynamic multi-channel environment induces much time and power cost to the process [20]. The route establishment involves a partial or network wide route request broadcast and reply process while the constructed routes are expected to be stable and reliable to avoid frequent re-routing which is prone to induce broadcast storm, radio resources waste and degradation of end-to-end network performance such as throughput and delay [21], [22].

1.1 Network Coding

In network coding, data packets are encoded by intermediate nodes and are then decoded at the destination nodes. Network coding has been successfully applied in a variety of networks including relay networks, peer-to-peer networks, wireless networks, cognitive radio networks, and wireless sensor networks. Network coding can be used to improve the throughput and spectral efficiency of wireless communication [19]. NC has many advantages, such as increasing the throughput by communicating more information with fewer packet transmissions.

1.2Implementation of NC

NC has been applied at various layers of the OSI model, such as the Physical layer, MAC layer, Network layer, Transport layer, Application layer. Network coding has also been applied in cognitive radio networks [14–18]. In CRN, there is a requirement of efficient and effective transmission of data by SUs, so that SUs can maximize the utilization of available spectrum. For this, NC has been applied to CRN to increase the throughput of CRN by reducing the transmission time for SUs. NC is also applied in CRN in order to allow multiple SUs to utilize the spectrum at the same time for a more effective utilization of spectrum [15].

2 LITERATURE SURVEY

Our research survey has been conducted on cognitive radio and network coding. However, the dynamic unpredictable spectrum accessibility in cognitive radio networks introduces new challenges for network coding in cognitive radio networks. In this section, we review and analyze the existing works on network coding and cognitive radio network.

JOSEPH MITOLA III [1] is the founder of "Cognitive Radio" (CR). The term was intended to describe intelligent radios that can autonomously make decisions using gathered information about the RF environment through model-based reasoning. Lu Lu, et.al [5] provided an overview of recent research achievements of including spectrum sensing, sharing techniques and the applications of CR systems. Gin-Xian Kok, et.al [6] proposed the Network Coding Routing (NCRT) protocol which consists of a new set of coding conditions, and a new routing metric that takes into consideration both coding opportunities and network workload. Wei Mu, et.al [7] considered a cognitive radio network where secondary users (SUs) employ network coding for data transmissions. SU transmission time is reduced due to network coding. And it increases spectrum availability to SUs. S. B. Mafra, et.al [8] investigated the performance of a network coding based secondary network in a CR system under spectrum sharing constraints. Ralf Koetter and Muriel Médard [9] observed the issue of network capacity. They extend the network coding framework to arbitrary networks and robust networking. For networks which are restricted to using linear network codes, they find necessary and sufficient conditions for the feasibility of any given set of connections over a given network. Christina Fragouli et.al[10] proposed an instant primer on network coding. They explain what network coding does and how it does it. They also discuss the implications of theoretical results on network coding for realistic settings and show how network coding can be used in practice. Shuoyen Robert Li et.al [11] considered a multicast problem and proved that linear coding suffices to achieve the optimum, which is the max-flow from the source to each receiving node. Pouya Ostovari and Jie Wu [12] proposed two dynamic network coding schemes that achieved the maximum throughput and reduce the number of required feedback messages. Moreover, they proposed a fair dynamic network coding (DNC) scheme that performs a trade-off between the throughput and the fairness in terms of decoding delay and the number of decodable packets at different destination nodes.

Ibrahim Demirdogen et.al[13] employed Forward error correction (FEC) driven network coding (NC) method as a defense mechanism. Their method can efficiently contribute to network performance by improving BER, in the absence of any attack.

3 CHALLENGES OF NETWORK CODING FOR COGNITIVE RADIO NETWORK

In this section we provide a summary of network coding challenges in CRN. Cognitive Radio links are dynamically available and likely uni-directional, in the multiple-system coexisting environments. The challenges of NC for CRN includes routing, Security, neighbor discovery.

3.1 Routing in multi-hop CR networks faces several new challenges. A unique challenge is the collaboration between the route selection and the spectrum decision [2][4][6][7]. In addition to node mobility, link failure in multihop CR networks may happen when primary user activities are detected. How to vacate the current spectrum band and to move to another available spectrum band quickly is still an unexplored problem.

The second study is on the **association and Security**. Security implementation is difficult to achieve due to the dynamic behavior of the network. NC is applied in CRNs to achieve security by detecting multiple types of attacks. One of the common attacks in CRN is PUE attack [12]. A physical layer NC is applied to maximize the available bandwidth utilization and to detect any malicious behavior by attackers [13].

3.2 Neighbor discovery is another case study in CRNs to ensure effectual communication amid multiple users. The author of [14] ensures the effectiveness of the neighbor discovery process by proposing an algorithm. It is highly distributed, the number of nodes does not need to be known in advance, and it can also be used to prevent a variety of jamming attacks.

4 APPLICATIONS OF COGNITIVE RADIO NETWORK USING NETWORK CODING

In this section we discussed the application areas of cognitive radio network using network coding.

4.1 Public Safety: CRN plays a vital role in public safety and emergency applications. Blue Force Tracking (BFT) consists of some GPS information that is periodically shared between all public safety workers during an intervention. Random Network Coding technique is considered to be the most adapted to the BFT service support in CRNs. GPS information are periodically collected by each node. There are two buffers for each node, one for native packet and other for encoded packets. Adapted Random NC protocol combines all the native packets from the native packet buffer before sending them to available nodes in the network.

4.2 Multimedia Applications (Commercial Use):

NC is applied in CRN to improve the quality and efficiency of commercial applications. Some authors designed framework for efficient multimedia multicast services in CRN. Their framework protects the rights of subscribed user and also improves the quality of video. Proposed framework applies NC and superposition coding to reduce the scheduling complexity and to account for heterogeneous channel conditions. NC improves the scheduling complexity by encoding all packets equally and thus base station does not differentiate among packets during scheduling. It improves the average received data rate and save the transmission time.

4.3 Tactical Networks:

Optimized transmissions reduce the power consumption and overhead. Multicast and broadcast transmissions can improve the efficiency and effectiveness of wireless links when transmitting multiple copies of messages using the radio broadcast property. Multicast and broadcast faces some issues in tactical networks such as military applications. NC for CRN solve these issues, the framework is based on intra-flow coding where the source node divides the flow in a sequence of equal size payloads.

5 CONCLUSION

Network coding in cognitive radio networks enhance the usability of spectrum in a network. In this paper we presented a survey of network coding techniques, routing protocols used in CRN and also discussed network coding in different layers for CRN. Then we present challenges and applications of NC for CRN.

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