

Network Coding Based Transport Protocol Variants in Cognitive Radio Network

Shine Let G, Josemin Bala G, Benin Pratap C, Magdalene W

Abstract: Cognitive radio network has recently got more focus in research due to lack of spectrum resources. The unlicensed users can perform communication in the licensed frequency band. In response to the behavior of licensed users communication, unlicensed users communication need to change from one frequency band to another band. In this communication paradigm, the performance of unlicensed users transmission control protocol gets degraded due to the features of cognitive radio network. To overcome this, several authors suggested quite a few modifications in the existing wireless transport protocol for cognitive radio network environment. This paper gives an overview of different transport protocols used for unlicensed user's communication in cognitive radio networks. Also, this paper deals with two different network coding algorithms such as dynamic generation size adjustment algorithm and modified joint generation network coding implemented in transport layer of cognitive-radio based communication. Simulation work is carried out in NS3, as the sensing time of unlicensed user changes the different quality-of-service parameters are analyzed.

Index Terms: Cognitive Radio Network, Congestion Window, Network Coding, Primary User, Secondary User, Transport Protocol.

I. INTRODUCTION

Cognitive Radio technology is introduced by Joseph Mitola III in 1999 to have sophistication in the radio layer of communicating devices [1]. This is an intelligent radio which can adjust its transmission parameters based on the available environment conditions. Cognitive radio is built on top of Software-Defined Radio (SDR) [1]. SDR technology has been implemented in various DSP and general purpose processors for varying coding techniques based on the processing of data, voice, image etc. Intelligence added to SDR is called Cognitive Radio. Cognitive Radio progression into network started in the year 2006. A device which is having communication and networking capability added with cognitive radio features is called Cognitive Radio (CR) node. A network consisting of CR nodes is called Cognitive Radio Network (CRN) [2]. As per the analysis done by FCC,

700MHz spectrum band allotted for Television broadcasting have not been utilized in fullest manner [3]. The UHF band (300MHz to 3GHz) is called 'sweetspot', which is highly utilized for various applications and the number of users are overcrowded. Over the years go by, finding a frequency band for new users is difficult. To overcome this spectrum scarcity, CR node can be used for various communication purposes.

Primary Users or licensed users (PUs) are users where fixed licensed frequency band is allotted for their communication. The users having CR nodes will able to use the licensed spectrum band, when the licensed users are not utilizing it. These users are called Secondary Users (SUs) or Cognitive Users (CUs) or unlicensed users [2]. PUs have guaranteed Quality-of-Service (QoS) for their communication and CUs are provided with best-effort QoS. When the PU arrives, CU has to vacate that spectrum band and move to another spectrum band [4]. Due to shifting of spectrum band, the end-to-end communication gets disturbed. The transport protocol has to maintain the end-to-end communication without any packet loss or connection drop. For every packet sent, the sender waits for the acknowledgement information from the receiver. If the packet is corrupted, sender will retransmit the packet. Hence it is called as connection-oriented protocol. The main functions of transport protocol are congestion control and flow control. The flow control mechanism helps the sender to transmit the number of packets based on the buffer size and the destination packet processing capability. Flow control will be adjusted mainly based on receiver device communication to transmitter. The number of packets transmitted should be adjusted based on the congestion in the network. TCP data transmission is divided into two phases: slow start and congestion avoidance [5]. In cognitive radio network, due to spectrum sensing and spectrum change, the end-to-end connection get disconnected [2] and the QoS parameters get affected. Many authors have implemented different algorithms to improve the QoS of SUs communication. This paper gives an overview of TCP on wireless networks, different protocols implemented in wireless network to maintain end-to-end semantics, discussion of different algorithms implemented and the research issues and challenges of TCP in Cognitive radio network.

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II. TCP PROTOCOLS USED IN WIRELESS NETWORK

When the communications moved from wired to wireless, the main characteristics that affected the wireless network are channel contention, signal fading, mobility and power limitations [6].

The wireless network considered can be infrastructure or infrastructureless (Adhoc). Due to these characteristics, TCP performance got effected due to segment loss and packet reordering. Many TCP protocols are implemented to provide solutions based on congestion detection approach, state suspension approach, response postponement approach and hybrid approach [7]. For congestion control in the network, TCP Tahoe, TCP Reno, TCP Vegas and TCP SACK protocols are implemented. Based on different application of data transmission a variation on the above protocols was done for communication.

Congestion Detection Approach is used to detect the packet loss caused by network congestion and therefore congestion window is adjusted based on the packet loss. Various protocols are implemented to reduce the packet loss due to congestion are TCP-Peach, TCP-Probing, TCP Westwood, TCP-Jersey and TCP-Casablanca. The general Congestion window adjustment [7] is shown in fig.1. Based on the above protocol, the quantities represented by '*' is varied. Based on the current-state network condition, end-to-end connection is suspended and resumed to avoid segment loss in state suspension approach. Freeze-TCP, Interlayer collaboration (ILC)-TCP, TCP-Feedback, Explicit Link Failure Notification (ELFN)-TCP and TCP-DOOR are the state suspension approaches. In response postponement approach, TCP client delays the communication to alleviate the problems in wireless networks. Various proposed techniques are Delayed ACK TCP, TCP- Adaptive Delayed Acknowledgement (ADA) and TCP-Delayed Congestion Response (DCR). Adhoc-TCP (ATCP) is based on hybrid approach and is implemented for infrastructureless wireless network.

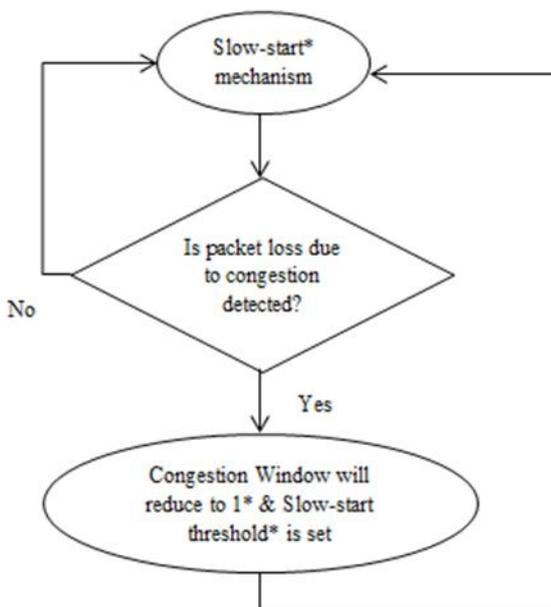


Fig.1 Congestion Window Adjustment

III. NECESSITY OF IMPROVEMENT IN CRN TCP PROTOCOLS

In cognitive radio network, end-to-end communication between users gets disturbed due to different characteristics in the CR network. The main functions of each node in CR network are shown in fig 2[8]. The performance of the TCP in CRN varies due to specific reasons such as PU behavior, Spectrum sensing and Spectrum changing.

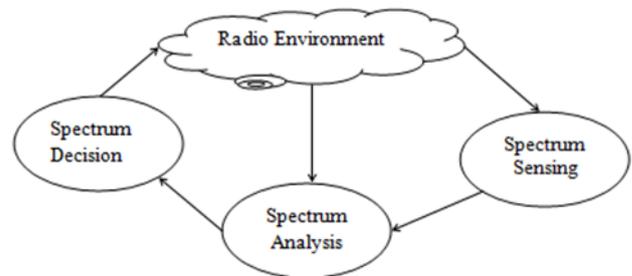


Fig. 2 Functions of CR node

PU Behaviour

Primary User is a licensed user gets highest priority in communication. When the PU arrives during the secondary user communication, secondary user have to vacate that frequency band and move to another vacant frequency band. This result in large amount of packet loss and the performance of TCP is affected. More number of retransmissions takes place due to PU behavior.

Spectrum Sensing

Every node in CR network performs periodical sensing of the available channel state. Each SU node, has two time slots: sensing time and transmission time.

In cognitive radio adhoc network, intermediate nodes are involved in data communication between any other two nodes. If any node is in sensing state, virtually the connection is terminated. The data packets received by that node are stored in the buffer. During sensing state, no transmission or reception of datapackets take place. This will affect the TCP performance. When the buffer overflows takesplace, there will be packet loss. Also, if intermediate node is in sensing, retransmission timer in sender expires and retransmission of the same data takes place, which leads to spectrum wastage and duplication of packets

Spectrum Changing

Due to primary user arrival, the secondary user has to move to new channel when the data transmission is proceeding. During spectrum sensing and spectrum changing, virtually the connection gets terminated. These are the main factors that affect the TCP performance during data transmission in CRN.

Many different protocols are proposed in the literature to improve the quality-of-service for SU data communication. The suggested protocols for TCP improvement are briefly explained and various parameters are analyzed and comparisons among those different protocols are seen in the following sections.

IV. THROUGHPUT IMPROVEMENTS IN COGNITIVE RADIO NETWORK

Various modifications has been done in the existing TCP protocols such as TCP newReno, TCP Vegas, TCP Westwood etc. for having efficient transmission in Cognitive radio network between secondary users.

The following are the few works done by different authors to improve throughput by considering various challenging factors in CRN.

A. Modifications based on PU Behaviour in CRN

In [9], the authors proposed an event driven transport protocol. This protocol is an extension of WTCP in wireless network. TCP Reno protocol is considered for the implementation of PU-Interference handler, faster recovery handler and RTT adjustment function. Throughput was analyzed based on PU activity ratio and bandwidth capacity. Other quality of service such as end-to-end delay, packet loss etc. was not analyzed in this work. This event driven protocol can be extended to a completely mobility based wireless environment.

The authors in [10] proposed an equation based on friendly rate control transport protocol for cognitive radio network. PU activity is considered from FCC spectrum database. Data transmission rate is varied based on PU activity in TCP friendly rate control (TFRC) protocol. In this, the throughput and goodput are analyzed. This protocol can be extended for changing spectrum related events instead of PU activity considered from spectrum database.

B. Modifications based on Spectrum Sensing in CRN

TCP CRAHN implemented by Kaushik R. Chowdhury et.al [11] considered the effect of spectrum changing, spectrum sensing and PU behavior. TCP CRAHN is implemented over TCP newReno considering six states of operating modes in cognitive radio network. Six states are connection establishment, normal state, spectrum sensing, spectrum change, mobility predicted and route failure. Throughput in normal state is equivalent to the throughput analytical expression of TCP newReno and is given by

$$B_n = \frac{\text{DATA}}{\text{RTT}} \sqrt{\frac{3}{2p}} \tag{1}$$

where DATA is the size of the TCP segment, RTT is the round trip time and ‘p’ is the probability of end-to-end packet loss.

In TCP CRAHN, throughput in each time slot is given by

$$B = \frac{B_n(1-P_s-P_c)T_p + B_s P_s t^2 + B_c P_c t_c}{P_s t^2 + P_c t_c + (1-P_s-P_c)T_p} \tag{2}$$

where P_s and P_c are probability that the network is in spectrum sensing state and spectrum changing state respectively. B_s and B_n are the TCP throughput in the spectrum sensing state and spectrum changing state respectively. Source node modifies the congestion window based on the available bandwidth. This CRAHN throughput analysis performs well but several assumptions are considered related to lower layer parameters [11]. TCP CoBA [12] works in same manner as TCP CRAHN except channel switching. In

[12], it is assumed that every secondary users can perform periodic spectrum sensing by using GPS function in it. This protocol updates congestion window (cwnd) based on the bandwidth variations and RTT (Round Trip Time). TCP CoBA receives feedback information from relay nodes in order to prevent bufferflow and to adjust cwnd size. With respect to fairness index, TCP CoBA outperforms compared to TCP CRAHN. Every node should be interfaced with GPS module to perform well during spectrum sensing is a challenging task.

1. Modified Network Coding for TCP

Due to spectrum sensing, PU behavior and spectrum decision retransmission rate will be high. In order to reduce retransmissions, network coding approach is used in [13-14]. In [13], TCP Network Coding-Dynamic Generation Size Adjustment algorithm (TCPNC-DGSA) is used, where group of packets are coded and is called generation size. Based on generation round trip time (GRTT), the next generation size will be adjusted. This algorithm reduces the retransmissions and improves QoS such as delay and throughput in CRNs. The flow chart of this algorithm is shown in fig 3. DGSA approach is to find the next generation size (EGS) [15].

In [14], the authors have proposed joint generation network coding (JGNC), where the generation size is adjusted based on the acknowledgement received by the sender node. The flow chart for modified joint generation network coding (MJGNC) is shown in fig 4. In both [13, 14], congestion window adjustment based on the GRTT is not discussed. If there is any packet loss due to spectrum sensing or PU behaviour, window size has to be adjusted. Fig.4 shows the proposed algorithm in [14]. The inputs to this algorithm are generation size (k), number of data packets to be transmitted (np), number of received ACK for the current period (Anew), number of the received ACK for the previous period (Aold). When np is greater than zero, an encoded packet is generated by the random linear combination of the original data packets from the current generation. At the receiver side, the coding vector is also received with the encoded packet. These coding vectors are stored in a matrix called decoding matrix. By reducing the decoding matrix to row echelon form rank is found. The calculated rank is sent to the transmitter. If the calculated rank is less than K, it shows that rank-K packets are lost. If those packets didn't reach the receiver because of interruption loss then after the sensing time the packets will reach the receiver. Even after if the packets do not reach, then the missed packets are joint with the next generation and encoded if difference between Anew and Aold is positive. Otherwise retransmission is done. This flow control mechanism is introduced in the JGNC algorithm. The Generation Size is gradually increased by 1 if the calculated rank is equal to K. The process continues till the availability of packets to be sent.



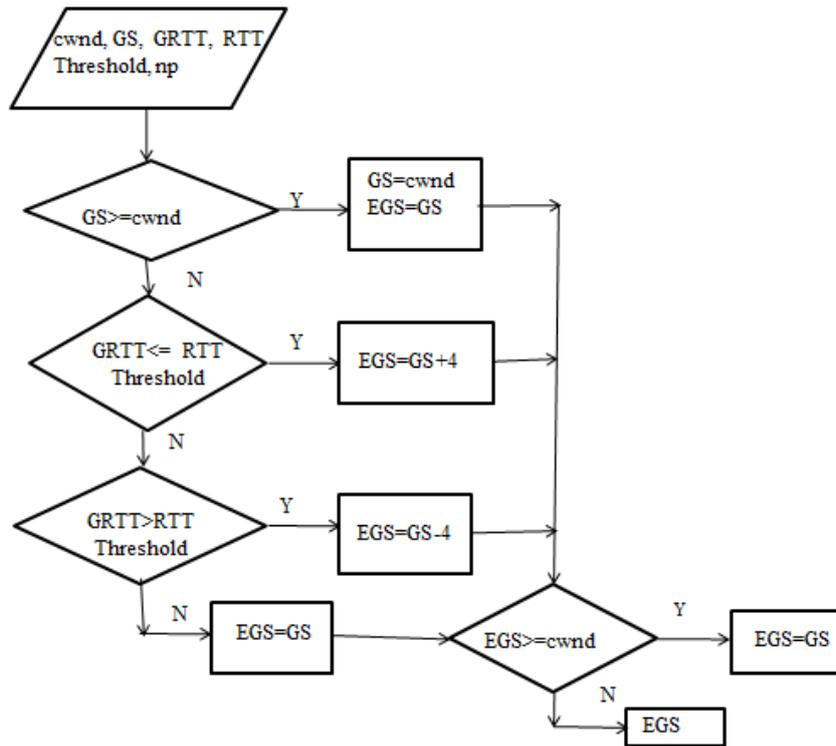


Fig. 3 DGSA Algorithm

where GS: Generation Size, EGS: Next Generation Size, RTT: Round Trip Time.

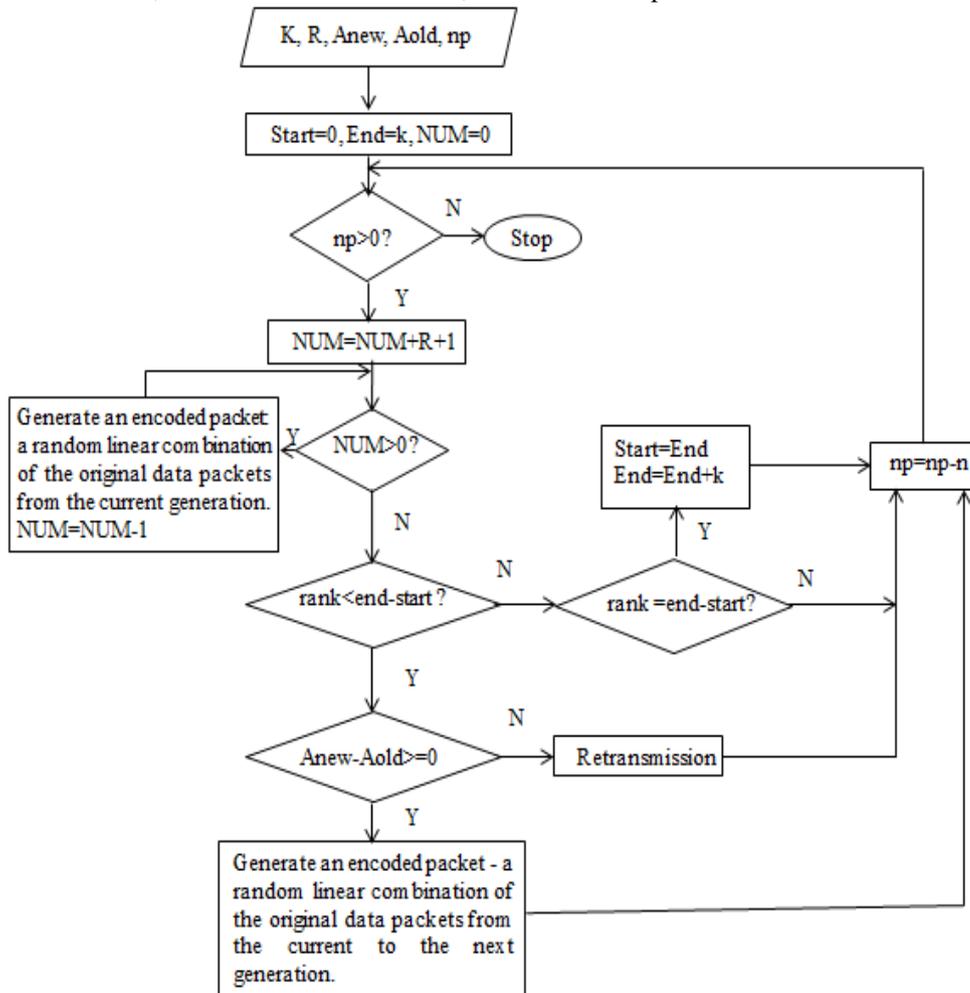


Fig. 4 JGNC Algorithm

V. PERFORMANCE EVALUATION

Most of the transport protocols used for cognitive radio network is simulated and verified in NS2, QualNet, NS3 etc. software. The results shown on fig.5 to fig.8 are obtained using NS3. The channel bandwidth considered is 2Mbps and the numbers of channels considered are 3 to 10. The comparison between [13, 14] with respect to sensing time and end-to-end delay is shown in fig.5 to fig.8. The throughput is analyzed for PU behavior and spectrum sensing state. Packet size is fixed as 1024 bytes and number of packets as 10. If the Sensing time increases, the time for TCP transmission is reduced, thus, the throughput correspondingly decreases. MJGNC algorithm shows higher throughput than DGSA algorithm because of reduced retransmission and is shown in the fig. 5.

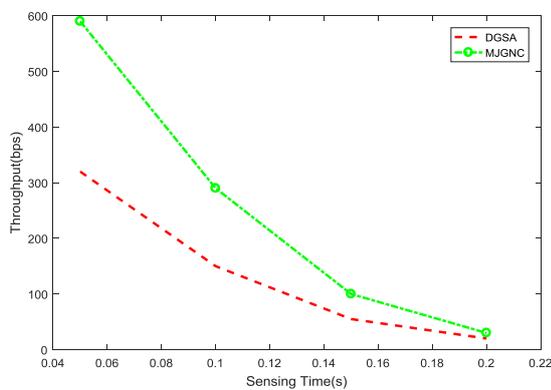


Fig. 5 Sensing Time Vs Throughput

End-to-End delay is analysed with respect to the sensing time and number of packets. As the sensing time increases, there will be packet loss which leads to retransmission of packets. Hence the end-to-end delay increases accordingly. In MJGNC algorithm, by reducing retransmissions shows lesser delay than DGSA algorithm as shown in fig. 6. The delay increases with the number of packets but MJGNC algorithm shows lower delay than the DGSA algorithm and is shown in fig.7.

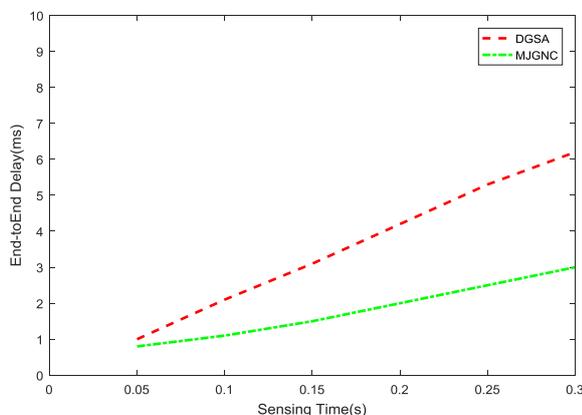


Fig. 6 Sensing Time Vs End-to-end delay

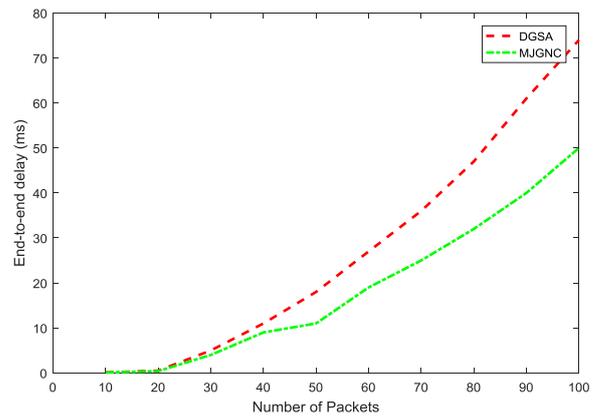


Fig. 7 Number of packets Vs End-to-end delay

Throughput is calculated with respect to the number of packets sent. Packet size is fixed as 590 bytes. The throughput linearly increases with the number of packets till reaching the bandwidth of the channel and then it is stable. MJGNC algorithm shows higher throughput than DGSA algorithm. It is shown in the fig.8.

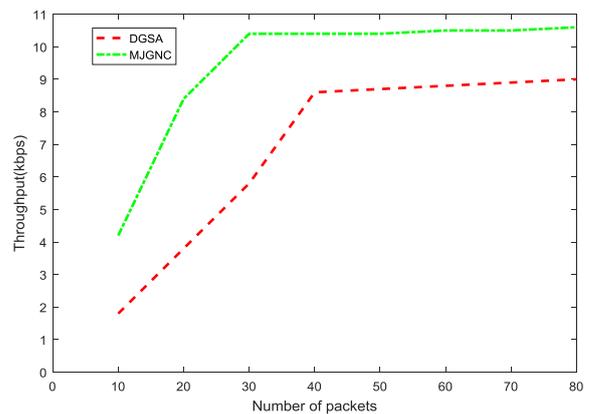


Fig. 8 Number of packets Vs Throughput

The transport protocol performance in CRN can be optimized by considering the Network layer and MAC layer together. The cross-layer approach can be effectively implemented in NS3 software.

VI. CONCLUSION

This paper gives an insight of various factors that affect the communication of unlicensed users in cognitive radio network. Many upgradations are done in traditional TCP protocols used in wireless network to perform efficiently in cognitive radio network. The performance of MJGNC algorithm is better than DGSA algorithm. The two TCP protocols discussed in section IV considered assumptions on lower layer parameters. To have good improvement in TCP protocol in CRN, the other layers interaction is also required. The future research direction shall include cross-layer design to improve TCP performance for unlicensed user communication.



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