Performance Evaluation of Transport Layer in Cognitive Radio Ad-hoc Networks

Sajjad Rahmani
Department of Computer Engineering
Sharif University of Technology
Tehran, Iran

A. M. Afshin Hemmatyar
Department of Computer Engineering
Sharif University of Technology
Tehran, Iran

ABSTRACT
In this paper, we have proposed some changes to MAC protocol for improving the performance of transport layer in cognitive radio ad-hoc networks. We have studied effects of different MAC and routing protocols on TCP in cognitive radio technology enabled environments. We have reviewed performance of TCP in two different situations. In first situation, all users are secondary users while in second situation both of primary and secondary users exist. We used CRCN simulator which is based on NS2. We added cognitive radio qualifications to different MAC protocols by sequential MAC method. This method appoints prioritized access for primary users in specified channels in offline mode with acceptable overhead. As we know, route failure is a notable problem in network layer so we handle different routing protocols in ad-hoc networks. We observed routing algorithms based on maintenance of multiple routes and periodic messages for route checking has appropriate effect on TCP performance. Simulation results shows our changed MAC protocols have better performance in Throughput, End to End Delay and Packet Delivery Ratio than prepared MAC protocol for CRNs.

General Terms
Cognitive radio, Throughput, Primary user, Secondary user, TCP.

Keywords
PDR (Packet Delivery Ratio), CRN (Cognitive Radio Networks), E2ED (End To End Delay), PU (Primary User), CRAHN (Cognitive Radio Ad-Hoc Networks)

1. INTRODUCTION
Most of the wireless bands are licensed bands. But some the wireless bands called ISM (Industrial, Science, and Medicine) bands are free for all users. Several researches show that with growing number of wireless devices, in near future there will not be any empty spectrum band for use and thereby the congestion is a big problem in ISM bands. In addition, many researches show that the licensed bands utilization is low; it means that most of the time, the licensed channels are unused [1]. So because of spectrum scarcity, cognitive radio technology appeared. In cognitive radio technology, there are two kinds of users, primary users and secondary users, which use the same wireless band [2]. Primary users whom have earned access priority by pre-ordering specific spectrum, while secondary users want to have free access to those. So secondary users should use reserve spectrum when there are no primary users. So if a secondary user is using any licensed band and concurrently one primary user wants to send data in same time, the secondary user should abandon the band and the primary user will be on. For implementation of cognitive radio technology, two methods are applied. In first method, which is call overlay, secondary users should leave the band when primary users are on. In the second method, which is called underlay, secondary users could use the band when the primary users are on, but introduced interference level of secondary users should be less than a specified threshold. Throughout this paper, we used overlay method and evaluated performance of several MAC protocols on transport layer. Three main parameters are considered: Throughput, End to End Delay (E2ED), and Packet Delivery Ratio (PDR). In addition, Effect of routing protocols on these parameters would be considered.

2. RELATED WORK
By saturation of ISM bands, CRN technology introduced to utilize licensed bands. Some surveys was done on CRNs and specific TCP protocols are introduced [3], [4]. One of them evaluated equation based TCP protocol [4]. Also collaborative and decoupled routing designs are introduced [5]. In addition, different metrics for routing in CRAHNs are analyzed [6]. Combination of on-demand routing and spectrum band selection is applied for CRAHNs [7].

3. PERFORMANCE EVALUATION
NS2-CRAHN simulator is proposed for performance evaluation of CRAHNs [8], In addition CogNS is another simulator for these networks [9]. In this section we evaluated performance of CRNs in CRCN simulator [10]. The metrics for evaluation are defined in the next section.

3.1 CRN PARAMETES AND PERFORMANCE EVALUATION
Quality of Service (QOS) is an important issue in real time wireless networks. So for evaluation of QOS three metrics are used, which are described as following:

Throughout: Rate of successful message delivery over a network.

End to End Delay (E2ED): The time taken for a packet to be transmitted across a network from source to destination.

Packet Delivery Ratio (PDR): The ratio of total received packets to total sent packets.

3.2 SIMULATION RESULTS

Throughput, E2ED and PDR for a CRN with parameters listed in Table 1 are simulated for different MAC protocols and the performance measures are listed in Table 2.

Table 1: CRN parameters without primary users

Parameter	Value
Traffic type	CBR
Connection protocol	TCP
Packet size	512 Byte
Number of channels	3
Dimensions of distributed nodes	50*50
Simulation time	50 sec
Number of TCP connection	6
Data rate	100 kbps
Routing algorithms	AODV
Number of primary users	0

Table 2: Simulation results for different protocols

MAC protocol	Throughput (bps)	PDR	E2ED
MACCON	26774.3	0.77	15.7
MACNG	36307.4	0.76	6.01
Simple	35147.4	0.76	7.96
802.11	59209.5	0.98	51.30

In the simulations, four MAC protocols are analyzed which are MACCON, MACNG, MAC Simple and 802.11. In MACCON protocol which is added in CRCN simulator, each node selects a channel form a free-channels list and each node doesn't know about the availability of channels for the other nodes. In this condition, collision is inevitable. In this protocol channel information is sent via packet header to physical layer. MACNG protocol also exists in CRCN by default and this protocol is free of collision. In this protocol, for transfer of data two phases are applied. In first phase nodes agree on selected channels, so in this protocol common control channel is applied for agreement. After agreement and selection of channels, the nodes will send their data. MAC simple is a basic MAC protocol which is implemented in NS2 simulator. MAC-802.11 is a standard wireless local area network protocol which is released in 1997 [11].

As seen in Table 2, MAC-802.11 has the highest Throughput and PDR among the protocols, but its large E2ED is not suitable in real-time wireless environments. So in the environment with co-existence of primary and secondary users, MAC protocols will have high delays and MAC-802.11 and MACCON will not have good performance in CRN.

Primary users are added in CRCN by sequential MAC method [12]. CRN parameters with primary users are listed in Table 3.

MANGEHANCED protocol is the extension of MACNG protocol which presented for CRN simulations. The performance of this protocol is compared to MAC simple and MACNG protocols which transformed to CRN environment by sequential MAC method. Simulation results in AODV, DSDV and DSR routing algorithms for MACNG are shown in Figure 1, Figure 2, and Figure 3.

As seen, AODV algorithm has the highest E2ED and the lowest Throughput among aforementioned routing algorithms. Because of keeping just one route in AODV, and high probability of route failure, this protocol needs to reroute continuously, and has poor functionality. DSDV has appropriate functionality because it keeps multiple routes between source and destination. DSR has the lowest delay.

Simulation results for AODV, DSDV and DSR routing protocols for MACNGENHANCED protocol are shown in Figure 4, Figure 5, and Figure 6.

As mentioned, MACNGENHANCED protocol is implemented for CRN applications in CRCN. The results show that DSR has the lowest delay and the highset Throughput. DSDV has the highest Throughput. AODV doesn't have good Throughput.

Simulation results for AODV, DSDV and DSR routing algorithms for MAC Simple protocol are shown in Figure 7, Figure 8, and Figure 9.

Table 3: CRN parameters with primary users

Parameter	Value
Traffic type	CBR
Connection protocol	TCP
Packet size	512 Byte
Number of channels	10
Dimensions of distributed nodes	2500*2500
Simulation time	50 sec
Number of TCP connection	21
Data rate	10 kbps
Routing algorithm	AODV, DSDV, DSR
Data rate	10 kbps
Number of primary users	0, 2, 4, 6, 8, 10

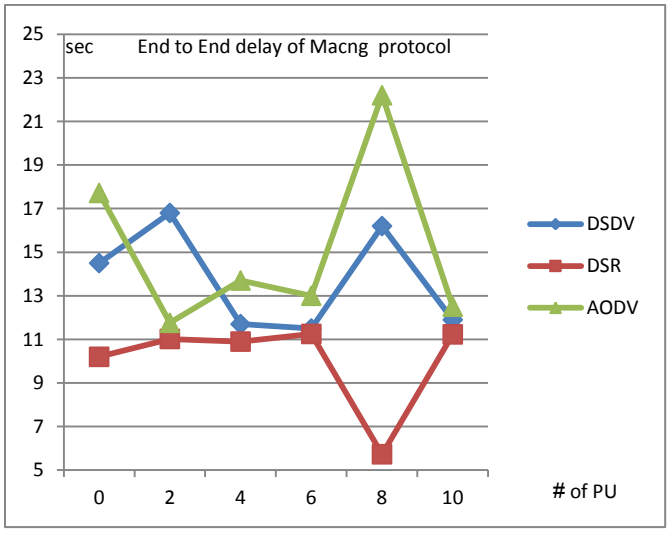

Figure 1: E2ED of MACNG

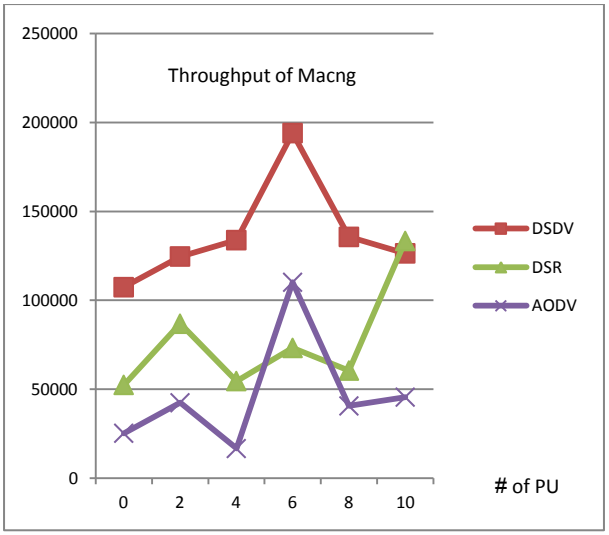

Figure 2: Throughput of MACNG

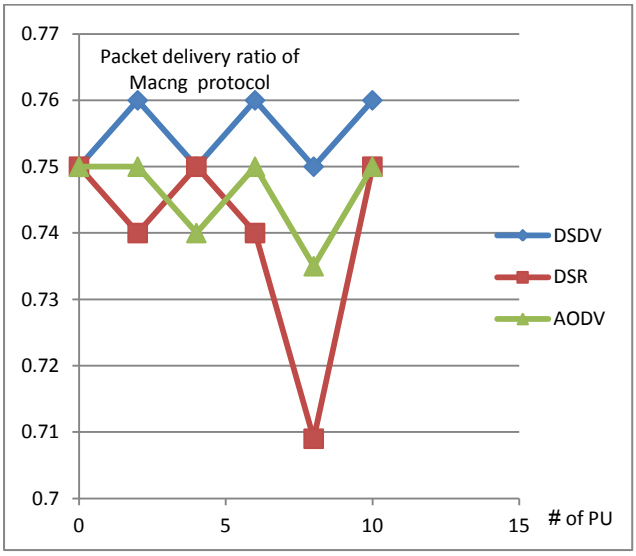

Figure 3: PDR of MACNG

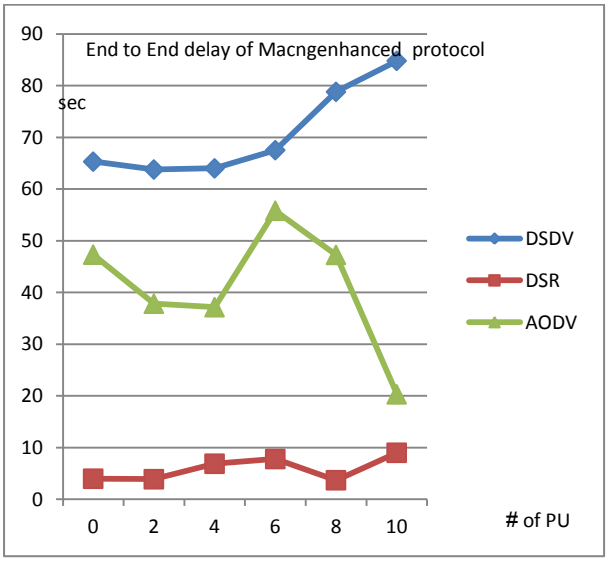

Figure 4: E2ED of MACNGENHANCED

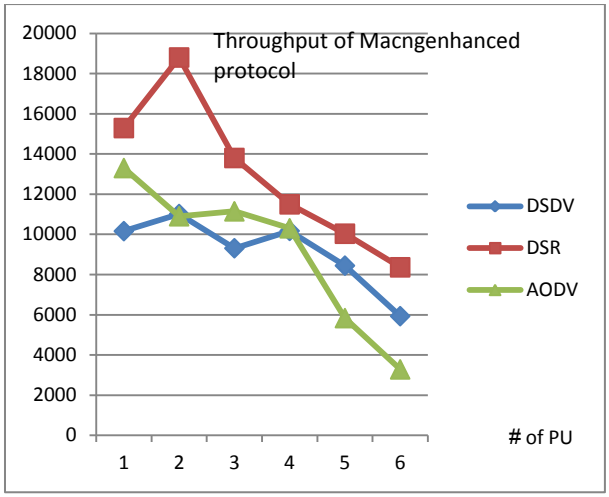

Figure 5: Throughput of MACNGENHANCED

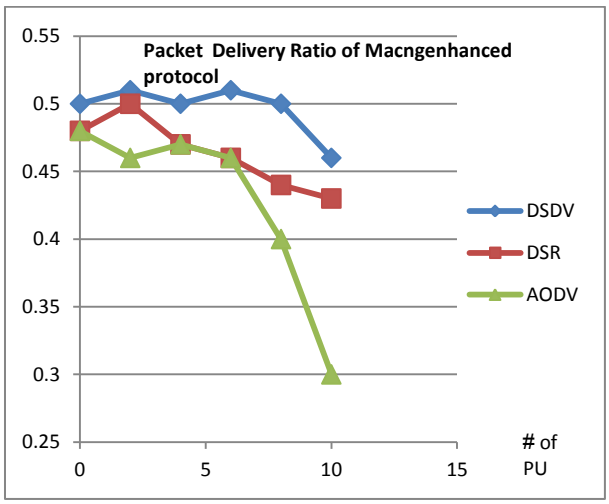

Figure 6: PDR of MACNGENHANCED

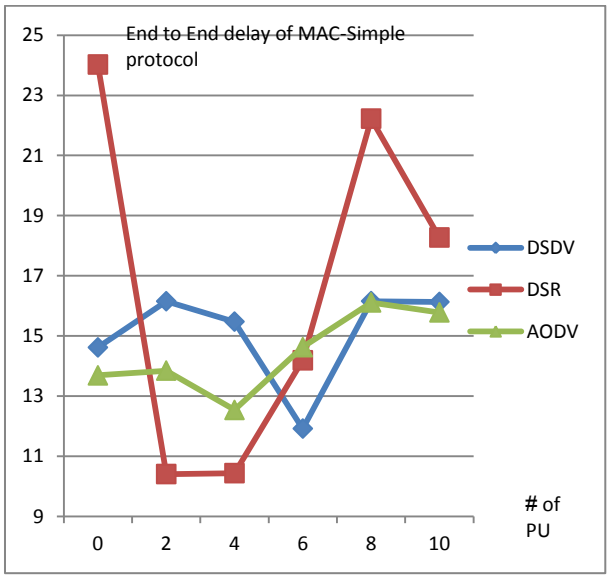

Figure 7: E2ED of MAC Simple

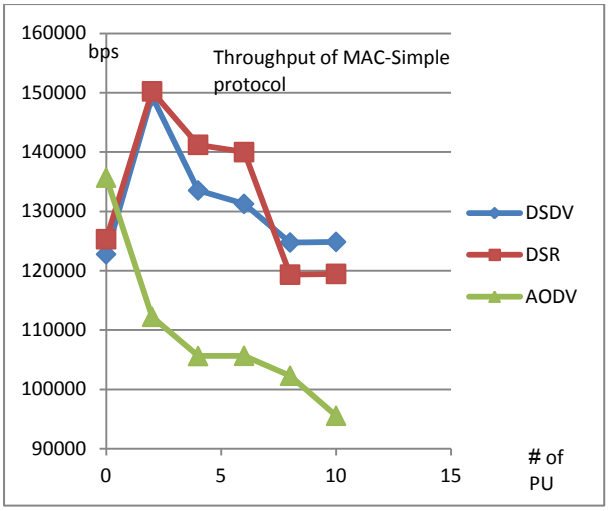

Figure 8: Throughput of MAC Simple

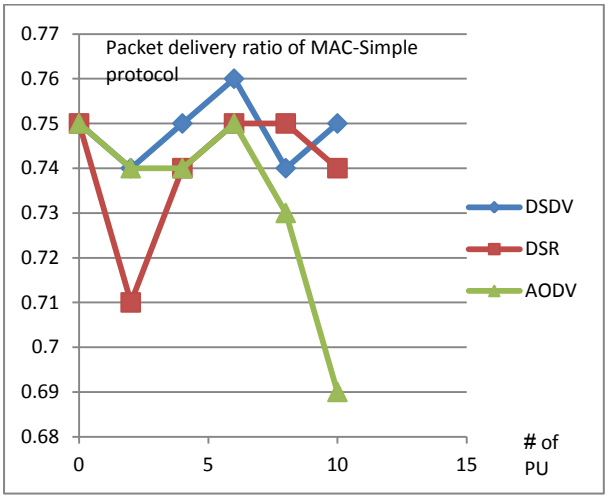

Figure 9: PDR of MAC Simple with primary users

As seen, DSR has high delay. DSR and DSDV have high Throughput. But AODV doesn't have appropriate performance.

4. CONCLUSION

It can be concluded that sequential MAC method for CRNs could apply good tradeoff between Throughput, E2ED and PDR metrics. This method applies offline changes in network. Also the changes in MAC layer causes to have less overhead and more optimization in network because it refuses to involving higher levels of network. In addition it can be concluded that AODV routing protocol doesn't have good performance in CRN networks. Also by implementation of multipath algorithms with exchange of periodic messages, better functionality in CRNs can be achieved. Although implementation of multipath routing algorithms may have high overhead, tradeoff between different parameters should be applied.

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