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Efficient Routing For High-Mobility Multi Hop Cognitive Radio Networks

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Abstract— In high-mobility cognitive radio networks (CRNs), the fast topology changes increase the complexity of the routing scheme. In this paper, we propose a novel CRN routing scheme that considers the path stability and node capacity. First, a realistic mobility model is proposed to describe the movement of highly mobile airborne nodes and estimate the link stability performance based on node movement patterns. Second, we propose a CRN topology management scheme based on a clustering model that considers radio link availability, and the cluster heads (CHs) are selected based on the node degree level, the average number of hops, and channel switching from member nodes to the CH. Third, we propose two new common control channel (CCC) selection schemes based on the node contraction concept and the discrete particle swarm optimization algorithm. Our simulation results show that our proposed CCC selection scheme has high throughput and small transmission time.

Keywords— CRN, SDR, Bird Flocking Model, Swarm Optimization & Node Contraction Scheme.

I. INTRODUCTION

Wireless communication is rapidly growing. However, wireless signals compete for a limited amount of spectrum in any given space. On the other hand, there exists much of the underutilized licensed spectrum in many places, which has motivated the emergence of cognitive radio networks (CRNs) and dynamic spectrum access. CRNs are networks that can sense their operating environment and adapt their implementation to achieve the best performance. “Operating environment” should be interpreted very broadly, and includes the signal propagation environment, node density, traffic load, mobility, and, in the case of DSA networks, available spectrum. While today’s wireless networks (e.g., WiFi) already use very restricted forms of cognitive optimization (e.g., rate adaptation) and spectrum agility (e.g., channel selection), much more aggressive adaptation.[1]-[3]. CRNs require a radio device that is very flexible, so it can radically change various protocol functions at runtime. By opportunistically using the available spectrum in CRN, the devices can gain access to more wireless bandwidth without violating Federal Communications Commission regulations. Most current CRN designs try to adapt the existing wireless network protocols while taking advantage of the dynamic spectrum access.

In a typical CRN, nodes are equipped with a spectrum-agile radio that has the capabilities of sensing the available spectrum bands, reconfiguring radio frequency, and switching to the selected new channels. We organize the nodes into clusters to reduce routing overhead. Despite the nodes’ high mobility, the cluster structure should be as stable as possible when the cluster membership changes, particularly when a CH changes. These changes adversely affect the performance of radio resource allocation and scheduling protocols. In a CRN, it is imperative to select a CCC for exchanging the control information among nodes. A CCC selection scheme based on swarm intelligence was proposed in “Swarm intelligence based dynamic control channel assignment in Cog Mesh”, which tries to form a local control channel in the network. Another local control channel selection scheme was proposed in “Distributed coordination in dynamic spectrum allocation networks and Topology management in Cog Mesh”, a cluster-based cognitive radio mesh network, which exchanges control information in a cooperated group or cluster. A novel control channel selection scheme was proposed in “Segment-based channel assignment in cognitive radio ad hoc networks”, which tries to form a control channel along the routes. [5]. However, these CCC selection schemes do not consider the transmission delay and throughput.

II. ARCHITECTURE OF CRN

A. Description of Architecture

The spectrums available for cognitive radio are:

1. Licensed Band Cognitive Radio.
2. Unlicensed Band Cognitive Radio.

This License band cognitive radio is capable of using bands assigned to licensed users i.e., Primary user has a license to operate in a certain spectrum band. This access can be only controlled by its base-station and should not be affected by the operations of any other unauthorized user. Primary base-station is a fixed infrastructure network component which has a spectrum license.[6] In principle, the primary base-station does not have any cognitive radio capability for sharing spectrum with cognitive radio users. However, primary base-station may be required to have both legacy and cognitive radio protocols for the primary network access of cognitive radio users.

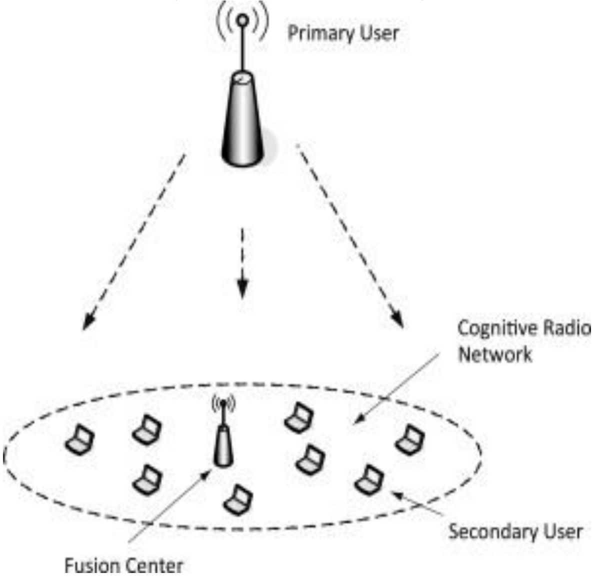

Fig. 1 Cognitive Radio Networks.

Cognitive radio user has no spectrum license. This can only utilize unlicensed parts of radio frequency spectrum. Hence, the spectrum access is allowed only in an opportunistic manner. Capabilities of the cognitive radio user include spectrum sensing, spectrum decision, spectrum handoff and cognitive radio MAC/routing/transport protocols. The cognitive radio user is assumed to have the capabilities to communicate with not only the base-station but also other cognitive radio users. Cognitive radio base-station is a fixed infrastructure component with cognitive radio capabilities. Cognitive radio base-station provides single hop connection to cognitive radio users without spectrum access license. Although cognitive radio was initially thought of as a software-defined radio extension (Full Cognitive Radio), most of the research work is currently focusing on Spectrum Sensing Cognitive Radio, particularly in the TV bands. The essential problem of Spectrum Sensing Cognitive Radio is in designing high quality spectrum sensing devices and algorithms for exchanging spectrum sensing data between nodes.[8] A simple energy detector cannot guarantee the accurate detection of signal presence, calling for more sophisticated spectrum sensing techniques and requiring information about spectrum sensing to be exchanged between nodes regularly. Increasing the number of cooperating sensing nodes decreases the probability of false detection.[15]

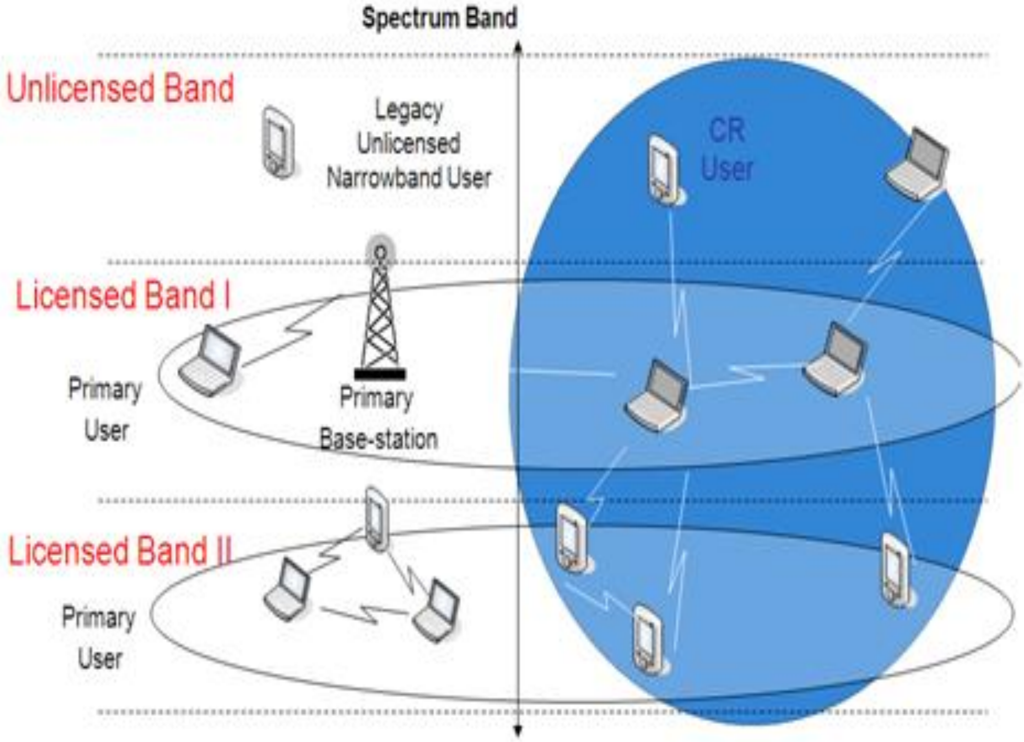

Fig. 2 Architecture of Cognitive Radio Networks.

III. System Model

Cognitive radio has the following characteristics

- First, it is aware of its environment and its capabilities.
- Second, it is able to independently alter its physical layer behavior based on its previous experience and its current environment.
- Finally, it is capable of performing the complex adaptation strategies according to the cognitive cycle. With these capabilities, when spectrum environment changes around cognitive user, it is capable of sensing these changes and independently changing its physical layer settings such as transmission power, channel selection and etc to meet some constraints or QoS requirements of the users.

A. Markov chain model

A Markov chain, named for Audrey Markov, is a mathematical system that undergoes transitions from one state to another (from a finite or countable number of possible states) in a chain like manner. It is a random process characterized as memory less: the next state depends only on the current state and not on the entire past. This specific kind of "memorylessness" is called the Markov property. Markov chains have many applications as statistical models of real-world processes[12]. In the CCRN, each communication node is usually equipped with multiple antennas and these antennas are dynamically set to sending/receiving/idle status. The number of working antennas may be dynamically changed according to the arrival of PUs. Most of existing works ignore the practical and real configurations. To be best of our knowledge, there are no existing research works that model an infrastructure based cognitive radio networks for multimedia transmission. A theoretical analysis model for this network is strongly required to evaluate multimedia system performance in CCRN. In this paper, we studied an infrastructure based cognitive radio networks in which both access point (AP) and primary user base station (PBS) co-exist in the networks and the AP is acted as the center of slot allocation and data relay. Figure 3 shows the proposed infrastructure which includes three types of communications: between UEs within CCRN, from UEs in CCRN to the nodes outside CCRN, and from nodes outside CCRN to the UEs in CCRN. As described in Figure 3, the PBS manages all the PCs that can be freely used by the nodes of primary user equipment (PUE), while some idle PCs can be used by other second users in the CCRN. The CCRN consists of access points (AP) that connects user equipment (UEs). AP communicates with other nodes outside CCRN via either wire or wireless connections. All APs and UEs are equipped with multiple antennas.

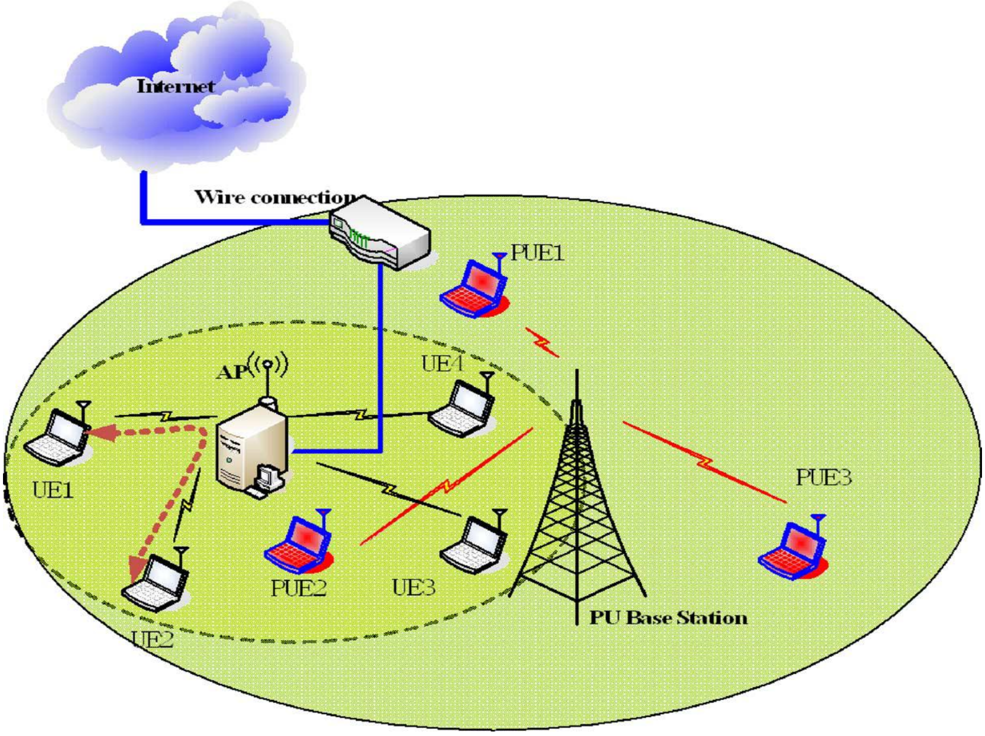

Fig. 3 Infrastructure of cognitive radio networks

B. Channel Allocation Schemes

In radio resource management for wireless and cellular network, channel allocation schemes are required to allocate bandwidth and communication channels to base stations, access points and terminal equipment. The objective is to achieve maximum system spectral efficiency in bit/s/Hz/site by means of frequency reuse, but still assure a certain grade of service by avoiding co-channel interference and adjacent channel interference among nearby cells or networks that share the bandwidth. There are two types of strategies that are followed:-

- Fixed: FCA, fixed channel allocation: Manually assigned by the network operator.
- Dynamic:
  1. DCA, dynamic channel allocation,
  2. DFS, dynamic frequency selection.
  3. Spread spectrum

C. Time Slot Calculation

Multiple slot allocation patterns can apply for different communication modes. For the communication among users in the CCRN, the number of time slots for the uplink allocated to the sender is equal to the number of time slots for the downlink allocated to the receiver. Because the communication between a user within CCRN and a node outside of CCRN involves both wireless and wired connections, we should consider the Difference for the time slot allocation specifically. In addition, both AP and UE need to exchange signaling information for the uplink and downlink.

D. Energy Model for CRN

Cognitive radio network plays an important role in improving energy efficiency in radio networks. The cognitive abilities have a wide range of properties, including spectrum sensing, spectrum sharing and adaptive transmission which are beneficial to improve the tradeoff among energy efficiency, spectrum efficiency, bandwidth, and deployment efficiency in wireless networks. Some works have been done to consider energy efficiency in cognitive radio networks. One of the CRNs most important characteristics is the ability that Cognitive Radio Users (CRU) has to dynamically access the spectrum. However, CRUs might be also capable of recognizing patterns of occupancy, to reduce the energy used for sensing, signaling and transmission. For this reason, Cognitive Radio technology has been also considered as an alternative to reduce energy consumption for wireless communications. The Power management for networks from a perspective has recently begun to receive attention from the conservation of energy for operating and environmental reasons. The implication of these factors is that most of the energy consumed in networks is waste

E. Active and Idle Power

A network element is active when it is actively processing incoming or outgoing traffic, and idle when it is powered on but does not process traffic. Given these modes, the energy consumption for a network element is:

$$E = p_a T_a + p_i T_i$$

Where, p_a , p_i denote the power consumption in active and idle modes respectively
T_a , T_i denotes the times spent in each mode.

F. Eigen Value Ratio Based Detection in CRN Networks

To design the energy efficient scenario for CR networks, we need to find how the consumed energy impacts the sensing accuracy. Sensing accuracy always depends on the number of samples N and the number of sensors K. The bigger of N and K are, the more energy consumed for each sensing. Here we take the Eigen value ratio(ER) based detection. Consider there are K collaborating secondary sensors and each sensor collects N samples during the sensing time. The collected samples from the K sensors will be forwarded to a fusion center for combined processing.

The combined $K \times N$ data matrix X is

$$X = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ x_{K,1} & x_{K,2} & \cdots & x_{K,N} \end{bmatrix}$$

Detection problem is based on two hypotheses: H0 and H1, where H0 denotes the target spectrum band is not occupied by a primary signal (available):

$$H_o : x_{k,n} = n_{k,n}$$

and H1 denotes the target spectrum band is occupied by a primary signal (not available)

$$H_1 : x_{k,n} = h_{k,n} S_n + n_{k,n}$$

Where k = 1, ...,K and n = 1, ...,N $n_{k,n}$ here is complex Gaussian noise with zero mean and unit variance. In [13], the vector $h_{k,n}$ typically represents the propagation channel between primary user and secondary users and s(n) stands for the source signal to be detected. The received covariance matrix is$R = XX_H$, where H is the Hermitian conjugate operator, and the largest and smallest Eigen values of this matrix are $\lambda_1$and λ_k respectively. The test statistic proposed for Eigen value based detection is $Z = \frac{\lambda_1}{\lambda_k}$.

Then Z is compared with the decision threshold γ to decide if the target spectrum resource is occupied or not. If $Z < \gamma$ the detector $H_o$outputs, otherwiseH_1. The decision threshold should be pre calculated which is determined by the distribution of the test statistic Z.

IV. Results & Discussions

Cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called **cluster**) are more similar (in some sense or another) to each other than to those in other groups (clusters). It is used in many fields, including machine learning, pattern recognition, image analysis, information retrieval, and bioinformatics. Cluster analysis itself is not one specific algorithm, but the general task to be solved. It can be achieved by various algorithms that differ significantly in their notion of what constitutes a cluster and how to efficiently find them. Popular notions of clusters include groups with small distances among the cluster members, dense areas of the data space, intervals or particular statistical distributions. Clustering can therefore be formulated as a multi-objective optimization problem. The appropriate clustering algorithm and parameter settings (including values such as the distance function to use, a density threshold or the number of expected clusters) depend on the individual data set and intended use of the results. Cluster analysis as such is not an automatic task, but an iterative process of knowledge discovery or interactive multi-objective optimization that involves trial and failure. It will often be necessary to modify data preprocessing and model parameters until the result achieves the desired properties.

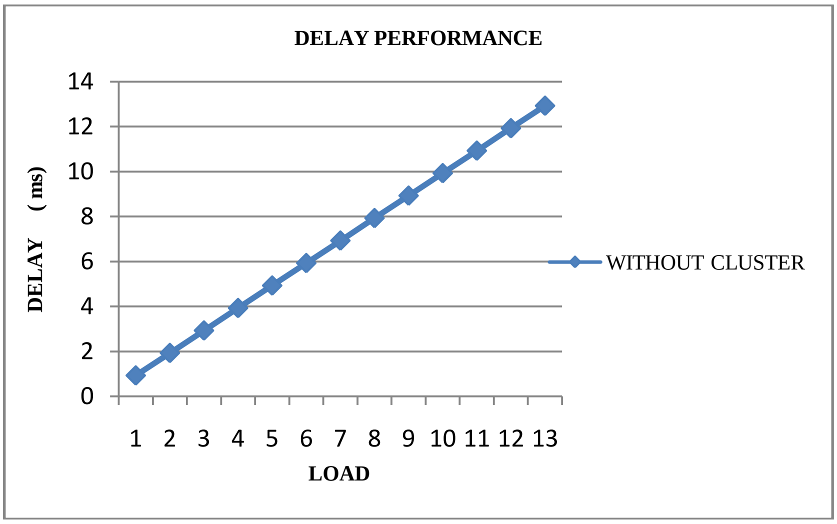

Fig. 4 Delay performance of without cluster formation

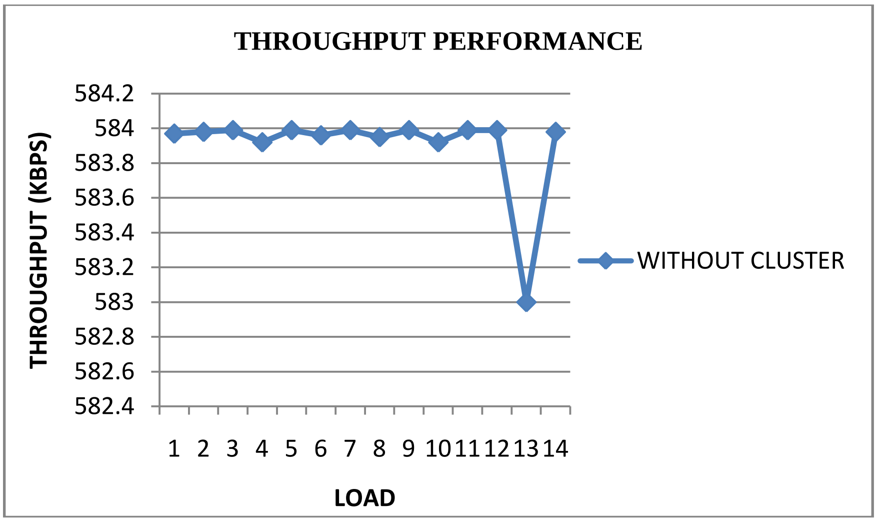

Fig. 5 Throughput performance of without cluster formation

Simulation results see from Figure 4 shows the delay performance of without cluster formation system. The delay also increases as the load increases. Simulation results see Figure 5 shows the throughput decreases when the load increases for the without cluster formation system.

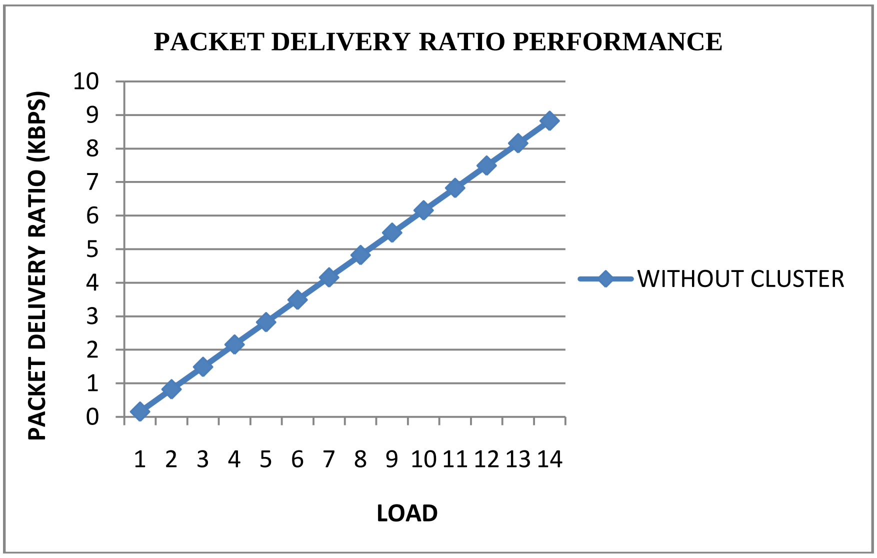

Fig. 6 Packet Delivery Ratio performance of without cluster formation

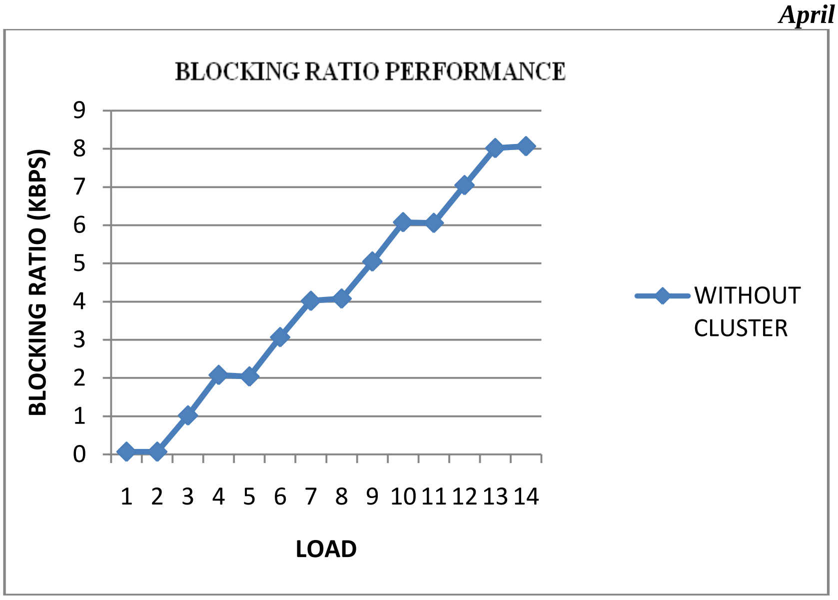

Fig. 7 Blocking Ratio performance of without cluster formation

Simulation results see from Figure 6 shows the PDR performance of without cluster formation system. The Packet Delivery Ratio reduces as the load increases. Simulation results see Figure 7 shows the Blocking ratio also shows poor performance for without cluster formation system.

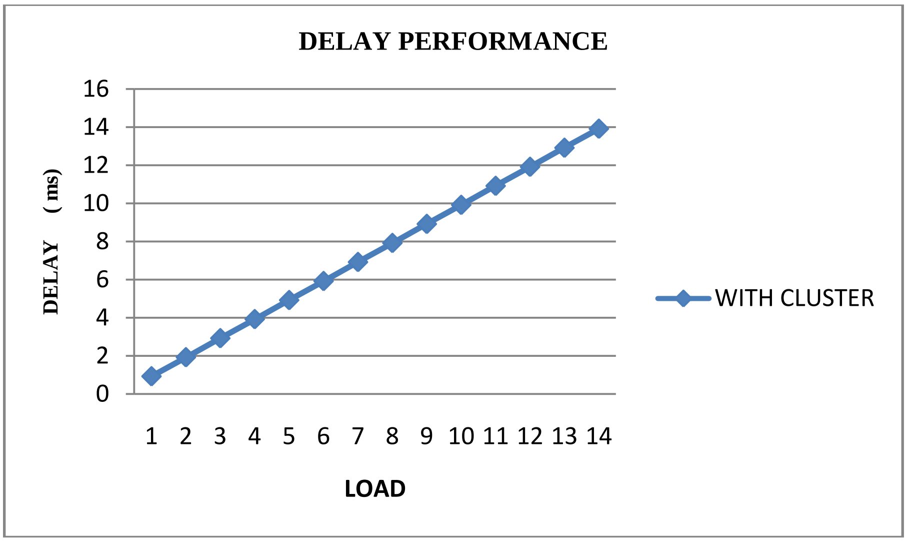

Fig. 8 Delay performance of with cluster formation

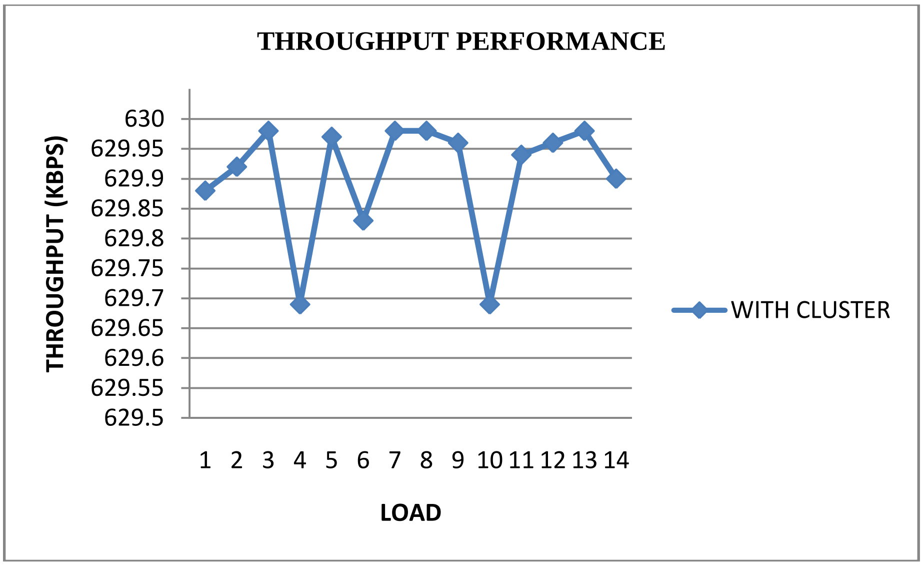

Fig. 9 Throughput performance of with cluster formation

Simulation results see from Figure 8 shows the delay performance of with cluster formation system. The delay is reduced as the load increases. Simulation results see Figure 9 shows the throughput also increases when the load varies from minimum to maximum.

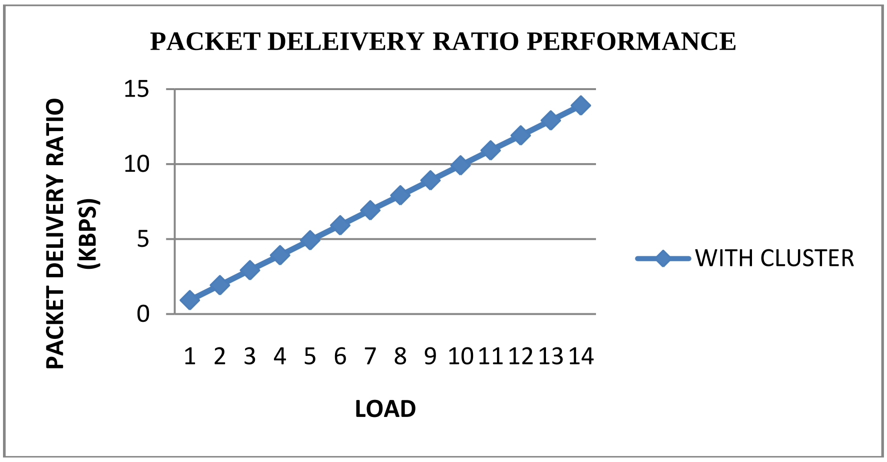

Fig. 10 Packet delivery ratio performance of with cluster formation

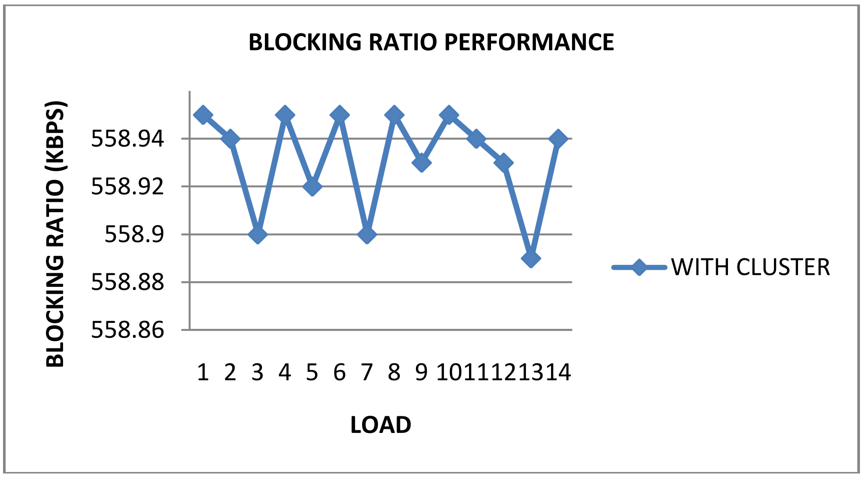

Fig. 11 Blocking ratio performance of with cluster formation

Simulation results see from Figure 10 shows the packet delivery ratio performance of with cluster formation system shows increase in its efficiency as the load increases. Simulation results see Figure 11 shows the Blocking ratio shows the increase in performance for with cluster formation system.

V. Conclusion

A novel routing scheme for a high-mobility CRN scenario by considering the path stability and node capacity is discussed. There by organizing the nodes into clusters to reduce routing overhead. Despite the nodes' high mobility, the cluster structure is as stable as possible when the cluster membership changes, particularly when a CH changes. These changes adversely show the best performance of radio resource allocation and scheduling protocols. The CRN path is based on link availability probability. A novel CCC selection scheme based on a new concept called "node contraction," which can quickly select a high-quality CCC among CHs is with cluster.Aiming at higher energy efficiency, current spectrum sensing algorithms are presented and Eigen value based detection is simulated to verify that the sensing accuracy increases as sensing energy consumption increases and reduces delay and increases throughput.

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