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Cluster Based Architecture for Cognitive Radio Network

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Abstract: Catastrophic events like flood often result in the derangement of the communication networks. The consequences include difficulty in locating the survivors of the disaster. The purpose of this paper is to give an insight to the design and development of a Cognitive Radio Network that can be used as an immediate remedy communication network which can help in such situations. The architecture based on clustering in adhoc mode is explored in order to develop an algorithm for implementing the cluster based cognitive network that focuses on yielding longer cluster lifetime. This implementation creates a cluster with less backbone network that improves the efficiency in routing and multicasting. By using the network simulation tools, performance analysis of this clustering architecture is done and the stability of the clustering based on the parameters and the relationship between the nodes and clusters is noted.

Keywords: Clustering, Spectrum Sensing, Cognitive Radio Network, Stability

Introduction

Centralized Cognitive Radio Networks (CRN's) are based on infrastructure in which Cognitive radio base stations control and coordinate the transmission activities of secondary users. The base stations coordinates the secondary user's transmission both in licensed and unlicensed bands by collecting spectrum-related information from the cognitive radio users. Based on the collected information, base station takes global access decision for all nodes. Example for centralized infrastructure based CRN is IEEE 802.22.

In the absence of centralized infrastructure, CRN's, Cognitive adhoc nodes in distributed CRN coordinate the spectral access decisions and share the available free channels. Thus, global mechanisms such as synchronization might be needed for spectrum access coordination. In addition, distributed cooperative detection and communication techniques are used to improve the overall network performance.

Wireless mesh networks is a popular solution for Internet access. In the wireless mesh network the challenge is less the wireless bandwidth available for requirements of applications which needs high speed internet. Spectrum aware access can be used to reduce the bandwidth problem by allowing the nodes to identify the available spectrum in dynamic manner. All the previous Cognitive RN applications have the secondary users using facilities of the primary.

Secondary users access the spectrum when primary is not using it. The sensing the channels for the SU's is process which should be done based on opportunistic spectrum channel access.

Natural calamities such as earthquakes, fires, or other unpredictable disasters usually disrupt the communications of the cognitive radio network. This cause the damage of the network either partly or fully which was previous connected and then it is result in disconnection. There should be some mechanism for urgent communications that will help the team of people in the rescue to provide help and to timely provide the efforts for reorganizing the networks and to locate the survivors of the disasters. Cognitive Radio Network can be used as emergency networks for providing the necessary help during natural calamities.

Literature Survey

A. Cognitive Radio Network Architecture for Fast Deploying Heterogeneous Networks

Recent advancements in cognitive radio has made the wireless communication systems efficient. The ability of cognitive radio to change the existing communication protocol according the wireless system demands makes it more suitable for wireless networks. One of application which requires the usage of CRN is the fast positioning of a heterogeneous wireless network used for forming a common communication platform between set of wireless devices which is not similar and in compactable. The paper gives an insight to the design and development of CRN used for constructing a fast positioning, frequency-shifting and non-homogenous wireless network. Cognitive radios can design a fast deployable heterogeneous wireless network (Tachwali *et al*., 2010) by inter-connecting heterogeneous wireless nodes which function as base stations with wireless terminals in closer proximity. The cognitive radio architecture designed in the paper is divided into three sub components: Digital transmitter and receiver, channel checking and sensing module and communication coordination module. The architecture of cognitive radio network is composed of three components, as shown in Fig. 1.

The communication coordination module takes the input from the sensing module for regulating the operation and the coordinate the activities of the Radio Frequency front end and digital transmitter and receiver. The communication coordination module act a centralized controller for all the activities done by all components. The decision on the placing cognitive radio is depends on digital transmitter and receiver modelling and ability to cope up to changes is controlled by other components. The RF front-end has input characteristics which include gain, frequency and filter bandwidth.

Input features of the transmitter and receiver finds the active components in the processing mode. They have a set of blocks in accordance with lower most layer of the architecture.

Output features of the transmitter and receiver gives measurement of efficiency that is managed by CRN. As shown in Fig. 1, one data flow starts from the digital transmitter and receiver to the spectrum monitoring for finding the free channels available.

Another data flow is among the digital transmitter-receiver and Input/ Output devices and in the transceiver and communication coordination module which controls the overall operation of system. The communication coordination module is most critical module in the architecture which has to be maintained properly.

The communication coordination module system does following important task in the cognitive radio architecture modelling:

- Obtaining proper transition decision in accordance with values provided by the performance measuring subsystem
- Controlling the process of scanning the spectrum and finding free channels for communication

B. Cognitive Radio Networks Architecture with Cross Layer Features

The author's present's architecture (Ju and Evans, 2011) with cross-layer features for CRN. The architecture allows the nodes to transmit and share network status through a common database to three lower layers and the processing of shared information is done by cognitive engine. The routing function of the network layer is also done by network layer.

Figure 2 shows the COGnitive NETwork architecture. Compared to TCP/IP model, there is no additional layers added to the architecture and the basic functions of each layer is same as the conventional model. So the frame/packet format of the transmitted packets are not changed. The modification is in attaching a common internal database for performing cross layer functions with shared data. In addition to the features provided by the existing cross layer architecture, the difference in this architecture is presence of learning engine, which senses the free channel available for database.

Every cognitive node has independent database which allows the cognitive engine to do learning process in distributed manner. The paper defines the functions of each layer as follows. The physical layer performs the task of transmitting raw bits and performs task of calculating the bit error rate. The MAC layer improve the reliability of link and performs error control. The network layer performs routing and addressing. The cross layer architecture is created by having direct communication between the layers, sharing database between the layers and creating new interfaces. These are advantages of this architecture.

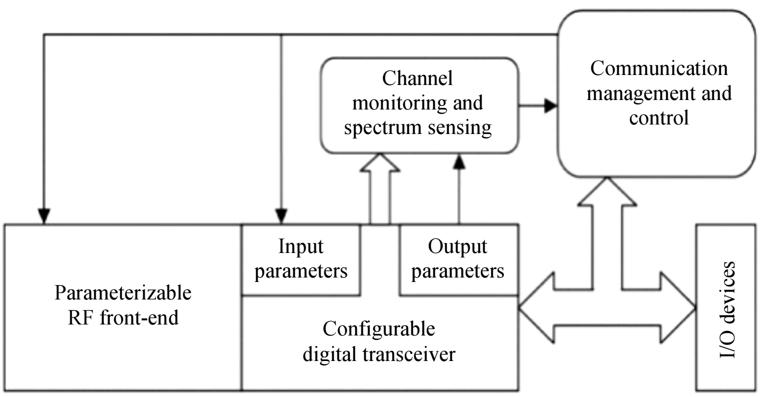


Fig. 1: Cognitive radio architecture

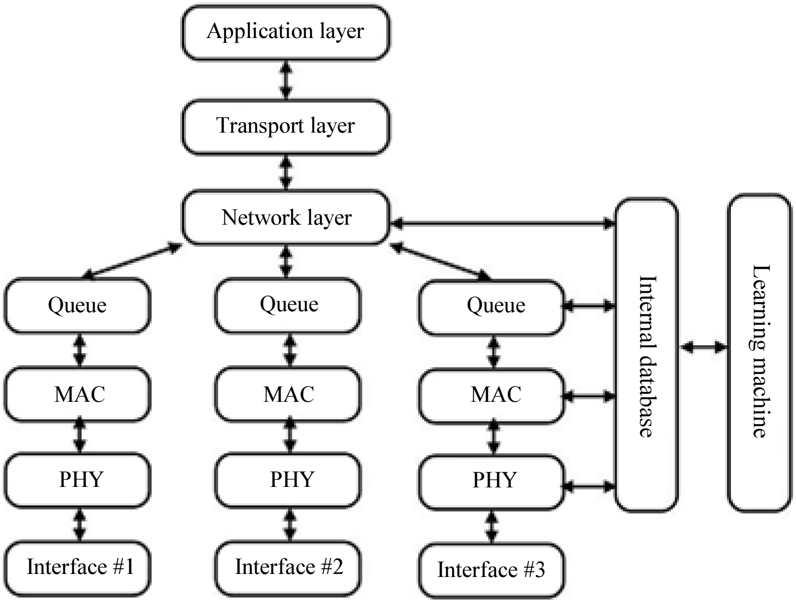


Fig. 2: CogNet architecture

The internal database contains the network information like average and deviation of the received signal strength from PHY layer and data rate collected from MAC layer. The shared information stored the database should be accurate and updated at regular intervals. The learning machine present in cognitive engines does four estimations for estimating the frequency types, estimating the probabilities of data transmission rate and loss rate, estimation of incoming data and estimation of improvement in throughput.

C. Database Network Framework for Cognitive Radio Networks in Adhoc Mode

Multiple hop CRN, accumulating meaningful information in the outside the architecture major job nodes should do individually and collectively for cooperation among the components of the network and for collaborative sensing capability. This paper proposes Database-driven framework (Khan *et al*., 2012) for collaboration and knowledge accumulation in CRN. The architecture is a database driven whose main goal is making use of collaborative spectral sensing performed by cognitive radio nodes and cooperation for creating a proper network architecture. The information obtained from the database driven architecture is made use of sensing and understanding operation. The Database driven network architecture helps the cognitive nodes to support the architecture and make awareness among others for discovering the information to work better.

The paper introduces an advanced architecture of a Cognitive Radio node which operate on adhoc mode as shown in the Figure 3. The architecture components are physical layer based on SDR and a MAC layer which is also based on Software Defined Radio, an Engine which perform learning of the free channels, Database driven components and component controls and framework for exchanging data. The frame work for exchanging data is a low overhead messaging framework for communication between processes and appropriate for a Cognitive Radio architecture in which components works alone and have in effecting data transfer of other components. The cognitive engine decides on operation of physical layer and improves the run time performance of cognitive radio node and adds the information Data base driven Manager components.

The database driven architecture for cognitive radio node provide all requirements for all the various layers of the protocol. The architecture collects the legacy information from different resources and stores in database. The current information based on the spectrum sensing done by the cognitive radio nodes. Legacy information contains individual nodes essential features and along with that the additional sensing information got from neighbouring nodes. More detailed database driven architecture is shown in Fig. 4.

Data Interface component helps to interact with various components of architecture and with components to extract the needed information. The various relevant information are collected and stored in the databases. In Fig. 4 we can see this the numbers 10, 11, 12.

The database is the major store house of information in the database driven network architecture. Database stores the raw facts also the essential high level information in various tables. Presently the relational databases are used for storing information about the radio spectrum and related data.

The Database driven architecture manager is the main coordinator and controller of the architecture. It provides proper interaction with the outside objects and components in the database. It also communicates properly the various operations happening in the architecture. The major information regarding the architecture is utilized by cognitive engine for sensing and understanding channel and make interaction to controller via data paths.

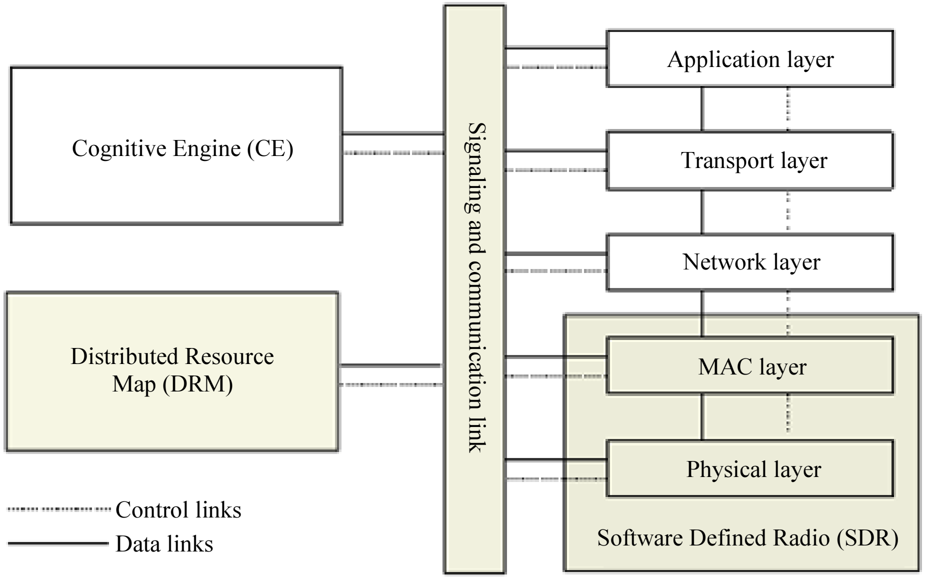


Fig. 3: CR node architecture

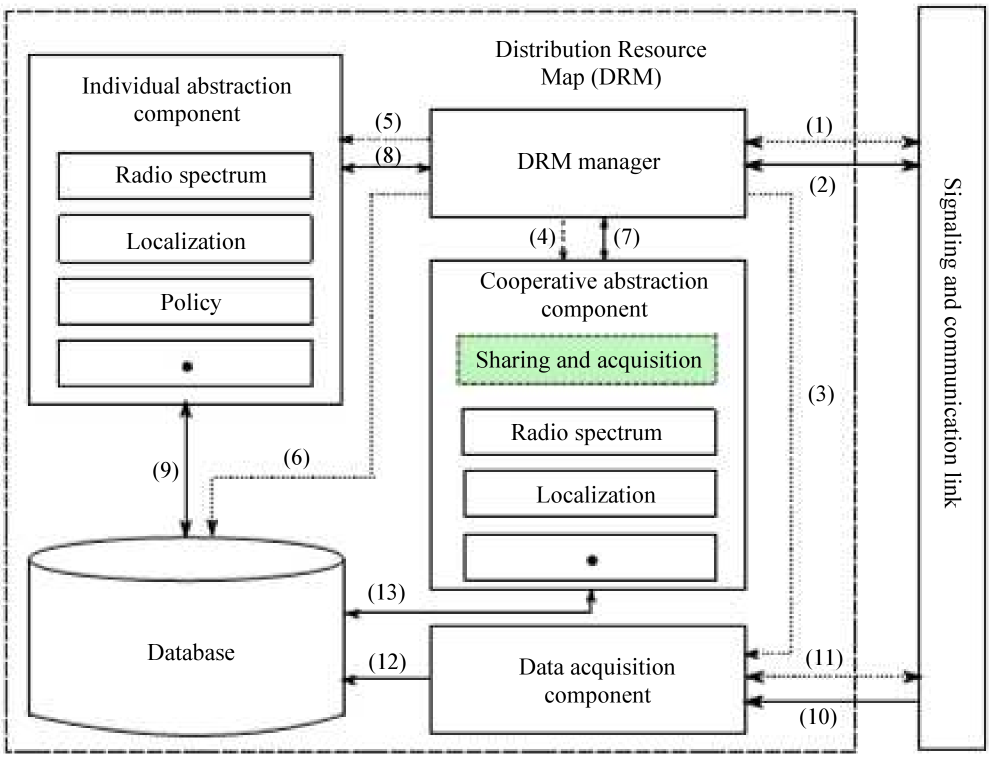


Fig. 4: DRM architecture

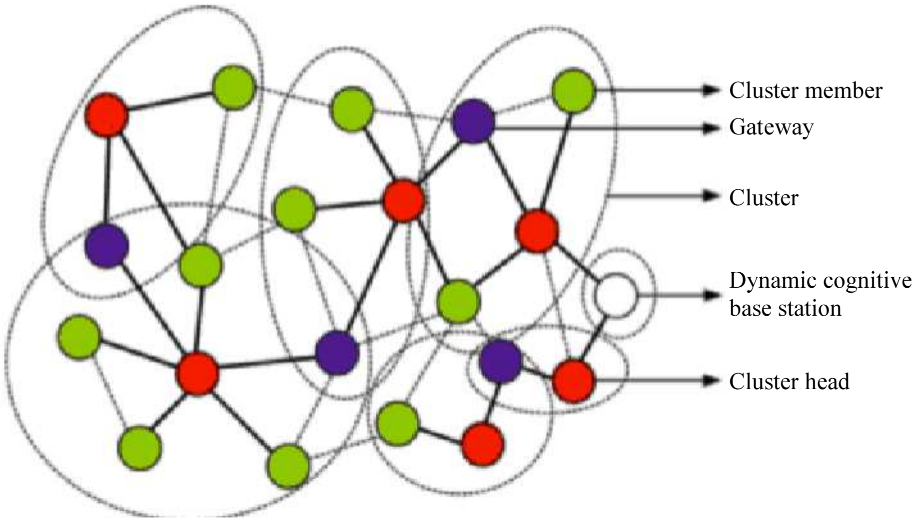


Fig. 5: Cluster based cognitive network

D. Architecture of Cognitive Radio Network using Clustering

The architecture based on Clustering in cognitive radio network provides improvement in mobility, balancing the network load and improving the overall performance of the network. The clustered architecture result in more stable backbone of cluster and simplified structure.it result proper control over the network and the protocols in the network architecture. This paper presents a constantly changing clustered architecture for CRN. Components of architecture are the head of the clusters, members and cluster gateway. The frequently changing fusion station act as the coordinator of the architecture.

The architecture classifies and organizes the networks into clusters which are in adhoc mode. Clusters are formed with the neighbouring components which are always mobile. Figure 5 shows the node with lower id forms the cluster base station in the architecture. One cluster contains single cluster base station only. Others contains head of the cluster, members and so on. Inside a cluster the head of the cluster and members are single hop neighbours. The multiple heads are connected by cluster gateways. The gateway coordinates the activities of the cluster heads.

The gateways are the communication channel for the different cluster heads. Cluster members cannot communicate with gateways.

Other than the cluster fusion station all other clusters are formed one coordinator head and other members. The communication inside the cluster is performed by the cluster head. The cluster head controls and coordinate the activities of the cluster. Before a new neighbour decides to come to the network, it sense the available spectrum before joining. After finding the channel the new nodes give the request to join the network. The neighbouring nodes receives this request message and an election process is done to find the winning node from the neighbours. If the head of the cluster is the winner, then the new node allowed to join the cluster. Then message send to node to join the cluster. If the new node is more is more than one hop away from the head then the node can try for becoming the gateway.

E. Distributed Cognitive Radio Network Architecture

Paper presents a distributed architecture for combined spectrum usage and routing, its implementation with Software-Defined Radios (SDRs) and its evaluation in a high-fidelity emulation testbed. CREATENEST, a comprehensive cognitive radio system, is built as an experimental prototype that provides a Cognitive Radio networking architecture (CREATE) for distributed support of cross layer optimization in cognitive radio networks and the Network Emulator Simulator Testbed (NEST) capability.

CREATE (Soltani *et al*., 2015) deploys a full protocol stack with distributed coordination (no common control channel) and local network state information and integrates neighbourhood discovery, spectrum sensing and channel estimation with joint routing and channel access implemented with backpressure algorithm. The backpressure algorithm is an ideal candidate for dynamic routing in spectrally diverse cognitive radio network without maintaining end-to-end paths. CREATE deploys a backpressure algorithm that is locally executed at each cognitive node to make the individually optimal routing and channel access decisions over different frequency channels.

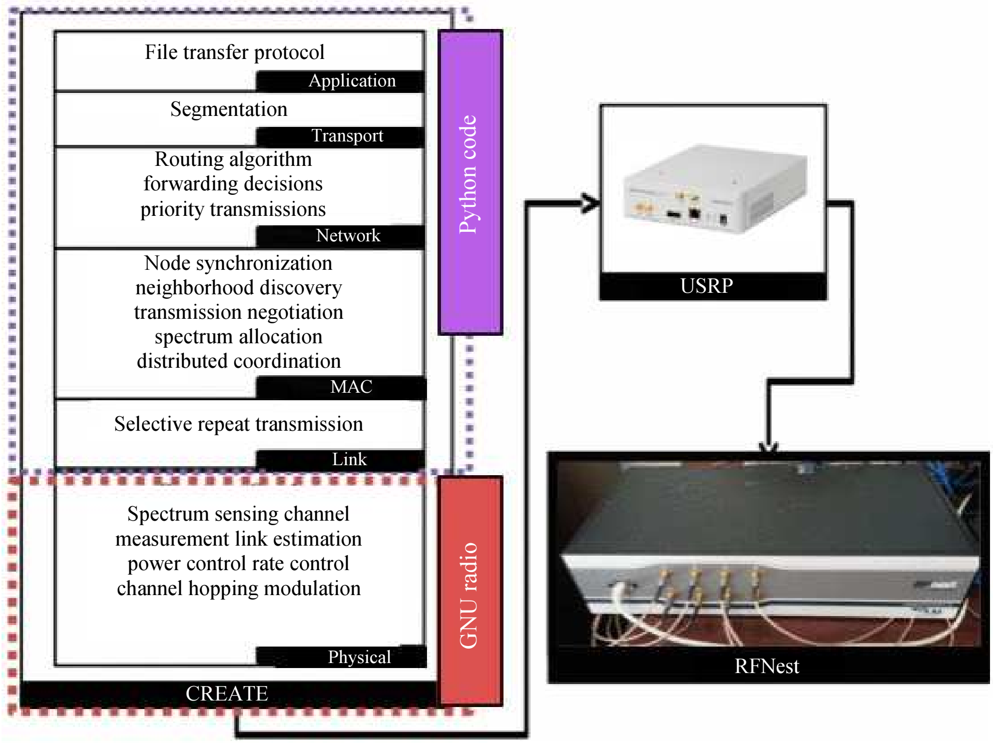


Fig. 6: The distributed Architecture using CREATE

CREATE establishes distributed negotiation and coordination channels (shared with data communications) and without synchronous means changes without the affecting changes in the network by finding relationship with the neighbours and modifying the information related to channel and queue. At each layer of the cognitive radio protocol stack, different protocols and functions are implemented by letting each cognitive radio operate with the same structure of protocol with similar functions. Along with application and transport layers for generating application traffic flows at each node, the capabilities implemented at the other layers are as shown in the Fig. 6.

Authors implemented distributed coordination functions operating in four phases.

Neighbourhood Discovery and Channel Estimation

A CREATE node enters this phase when joining the network for the first time and then later periodically. In this phase it broadcasts discovery (DIS) messages to announce its presence to its potential neighbours. Each node performs channel hopping which tries to visit each channel for a specific period of time.

Exchange of Flow Information updates and Execution of Backpressure Algorithm

In this phase, a CREATE node performs channel hopping such that the node visits a particular channel for given time and change another channel with different frequency. It then broadcasts SYN message on each channel visited to inform its neighbours about the status of its backlog.

Transmission Decision Negotiation

Based on backpressure decision, each node transmits RTS back to its neighbour over the assigned link/channel.

Data Transmission

A node enters the data transmission phase to transmit or receive data packets. For transmission, a node gets data packets from the selected queue at the transport layer and generates a DATA packet. Packets are transmitted either as raw packets or as coded.

F. Architecture for Testbed of Cognitive Radio Networks

Iris, an architecture (Sutton *et al*., 2010) that is modelled for cognitive radio network testbed with specific feature of re-configurability. This architecture is composed of in built features for run time changes on all the layers of the network. The architecture has properly designed interface for sensing the environment and contains built-in features for making decision about the changes in the existing environment of the network. This architecture is meant for all the layers of network protocol stack. It also gives an interface for creating configurable radio links and also the whole network of cognitive radios.

The test based is modelled as individual component based architecture. The different processing functions for discrete signal like filtering, modulator or demodulator are developed as components with common types of interfaces for data transfer, reconfiguration and overall life process control of the cognitive nodes. The various parts of the architecture are connected together to send and receive information which is linked to higher layers of the network to for a full network. In the architecture the components are represented in the Markup language, XML. The main advantages of using XML is that it is human readable even though there is complexity is there in graphs of data flow in the architecture. The Extensible Markup language provides a simpler interface for the cognitive radio.

The architecture is components include the Quadrature amplitude modulator, Radio controller, Parser for XML, Cognitive engine for learning and sensing the spectrum, Manager for individual components and manager for reconfiguration. When the architecture is implemented in software all the parts can be again configured. This helps dynamic spectrum sensing and management and proper functioning of Cognitive Radio Networks. The architecture provides support to all the layers of network protocol stack. The portable C++, runtime reconfiguration, proper interface for the controllers and support for multiple platform architectures are the other features of the architecture.

Iris engines are important components that states where the components are executed and how efficiently the nodes are modelled with different types of engines. The mode of execution of each node is decided by the cognitive engine which control and coordinate the individual component execution. The various cognitive engines uses different techniques for execution of the components, transfer of data between the components and provide higher flexibility to the designers. Cognitive Engines also support the higher layers of the protocol stack of the architecture. The architecture can be expanded to multiple platforms and its supporting the development of execution platforms.

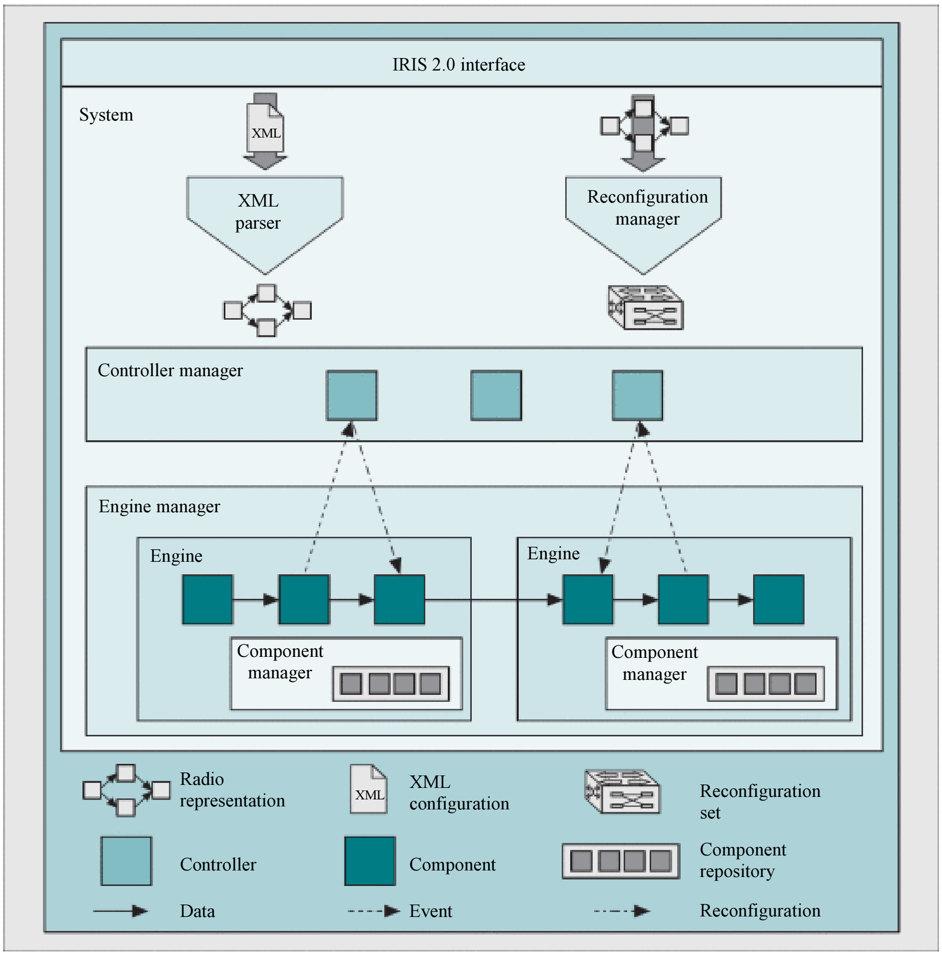


Fig. 7: Iris architecture

The architecture supports automated responses to reconfiguration events when it happens. One type of event is of internal type which is in response changes found in the components of cognitive radio. The events are represented by dotted line in Fig. 7. The elements of architecture which listens to events are called controllers. Controllers reconfigure the events in the system when required. The Manager for reconfiguration is responsible for the changes made. Iris architecture also support for external and internal triggers. Iris engines concentrates on flow of data, execution and reconfiguration. There will be multiple engines in the Iris architecture.

G. Cognitive Radio Networks Architecture based on Policies

This paper proposes new architecture for cognitive radio network based policy rules which can used for enforcing regulations on cognitive radio networks. The rules are forced based on preferences of stakeholders which aimed to achieve some specific features for cognitive radios. The radio are made to operate on certain frequencies and with some already defined features and parameters for transmission like modulation, power, frequency, coding so on. The policies can be in built and combined with exiting firmware. As the result the policies can only be made available to cognitive radio engineers and difficult to change.

The cognitive radio can be reconfigured on larger scale to separate policies from existing firmware. This methods results more adjustable and more flexible cognitive radio network behaviour. As a result policies are constantly changed from one stakeholder to another and can be placed on different cognitive radio terminals. The architecture allowing policy based network architecture has two parts policy. The architecture composed of two parts accomplishing spot and policy resolution spot as shown in Fig. 8. Policy accomplishing point has radio frequency transmitter and receiver and perform two jobs. The initial one is identifying the spectrum holes and calculating the position, time and free channels. When cognitive node needs to transmit, policy accomplishing spot initiates the request for policy and sent to policy resolution point. Policy accomplishing point regulate transfer according to reply got from policy resolution point after performing the reasoning. The reply can be of two types. They are positive and negative. If policy accomplishing point receives a positive reply it changes its configuration and begins its task based on the available condition. If the policy accomplishing point gets a not positive answer, it senses the spectrum. It gives the requirement for another policy from policy resolution point. After that new conditions are defined for configuration is got from policy resolution point.

If the conditions are proper, then policy accomplishing point should find the free channels by proper spectrum sensing and find new channels based on the conditions. Policy resolution point does the reasoning each every request is receives from policy accomplishing point. Policy resolution point contains two major components. They are policy resolver and database. The database save the policies which needs for specific nodes which originates from operator, use r and regulator. The policy resolver based on presently available policies decides on the policy request. It gives reply to the policy accomplishing point based on the policies present on the database. If all current rules are accepted, the transfer of permitted message is done. Otherwise if some of rules are not approved for the requested message, not permitted message is sent. The policy resolving point is also called as policy engine.

H. Network Architecture for Multiple Agent Self-Organised CRN

The authors propose network architecture which is called as multiple agent self-organised cognitive radio network (Qi *et al*., 2011). For improving the flexibility of cognitive radio, method to divide the network and network maintaining strategy is proposed. Authors propose self-organised network architecture with multiple agents in CRN. The complexity in process of learning the environment topology can be minimized by dividing the learning area into smaller paper. Division of area into smaller parts helps to make full use of capability of agents to find the allocation of the spectrum.

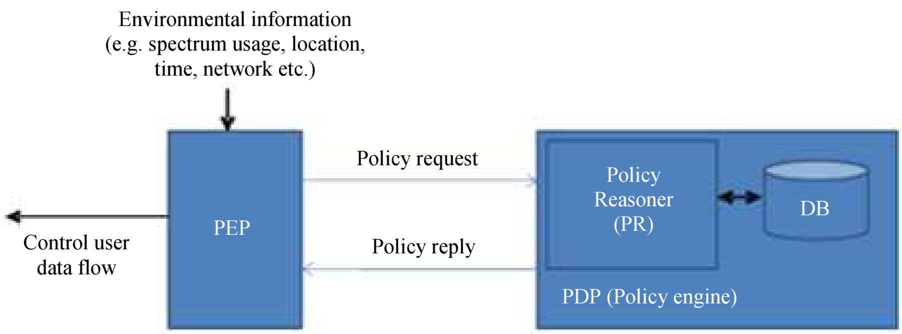


Fig. 8: Policy based reasoning system

For representing wireless nodes communication in uniform way authors model the agents intercommunication by using a modelling technique called graph colouring model. In this model nodes which are transmitting or communicating are given a permanent colour. When collision occurs during transmission, the collided nodes are represented by another colour as shown in Fig. 9.

The technique of self-organised cognitive radio network works on assumption that the coordinator stores the information about the location and others know only the behaviour of components with which they are interacting. Then the basic idea is that large network of cognitive nodes are divided to multiple groups. Each group has a master node which is elected by the members. The job of the master node is coordinate the behaviour of the group. The message passing or communication between groups is managed by gateways. The edges in between the nodes is called interference. so the interference should less as possible.

Figure 10 represents collection of different nodes. The first part is N1 which contains nodes from a to l. The second part is N2 which consists of nodes o, m and n and allocate the spectrum. The grouping is made as shown in the figure.

I. Cognitive Radio Network Architecture with Intelligence, Self-Organizing Capabilities

The paper presents the essential features of CRN architecture. Aim of the model in based on goals management of end devices. The architecture is divided into four major parts. They are goal management, intelligence management, self-organizing nature of architecture and reconfigurable nature. The architecture does functions to maintain these parts and allows communication among them and interfaces are provided to have interaction of cognitive radio network and the environment and to have an interaction among the parts of the architecture.

Figure 11 shows the CRN architecture (Xu *et al*., 2012) which is composed of four components such as goal management, intelligence management, self-organizing nature of architecture and reconfigurable nature. The most important part of the architecture is the goal management which govern the entire behaviour of cognitive radio networks. The absence of goal management component will lead operation of radio network will be affected badly and unwanted situations will take place. The intelligence management is needed for collecting information from environment and distributing them between other parts of the architecture. It provides better solution for current problems. The self-organizing nature of the architecture helps to take optimal decisions on the basis of collected information and goals. The reconfiguration nature is needed to again configure the features of architecture based the current situation and optimal decisions.

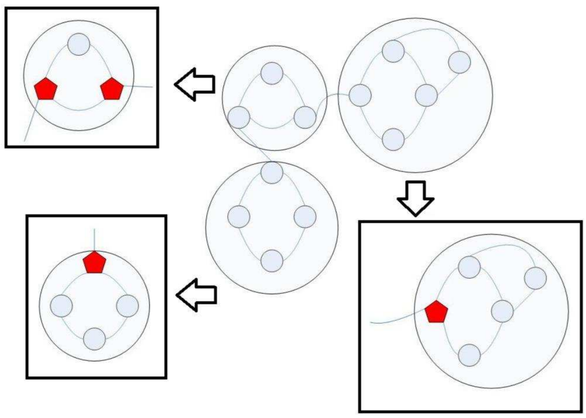


Fig. 9: Formation of groups

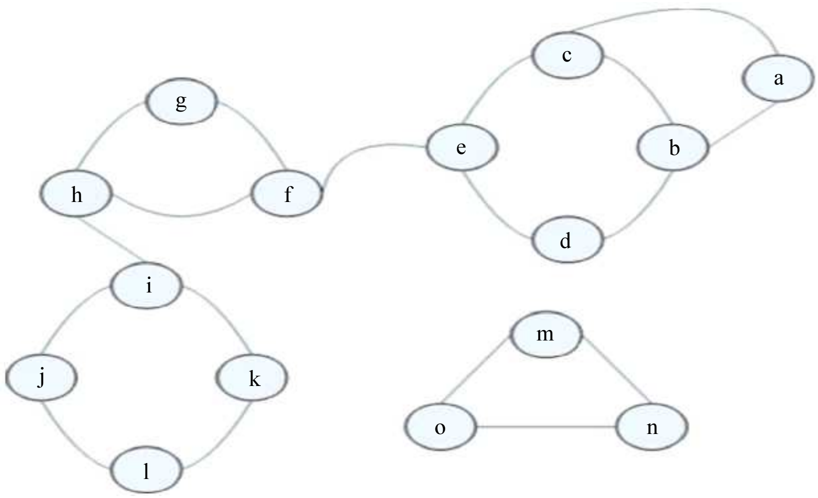


Fig. 10: Interference graph

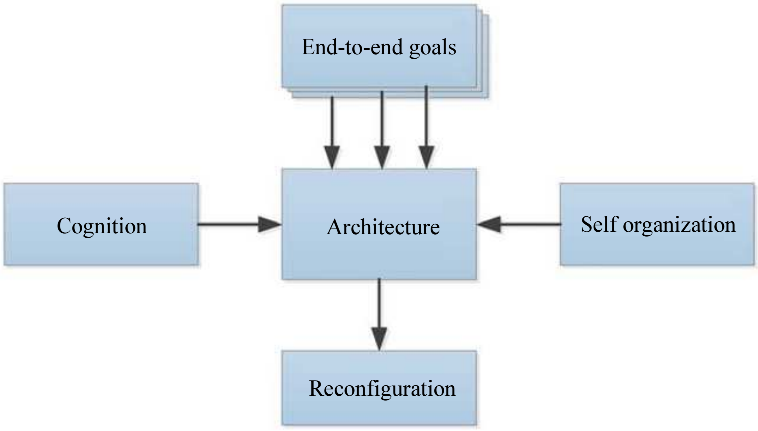


Fig. 11: Architecture with goals management, intelligent management, self-organizing nature and reconfiguration

Goals Management

Goals management part is composed of two subparts. They are end goals and intelligent specific language.

Intelligence Management

It is composed of five subparts. They are radio intelligence, network intelligence, user intelligence, policy intelligence, intelligence coordinator. The different subparts is needed to divide the intelligence functions in accordance with the importance and relation between the operations. By dividing into subparts the intelligence functions can be expanded and be classified into different modules.

Radio Intelligence

The radio intelligence component is needed for gathering information that cognitive radio network should be knowing. The information are about outside environment and inside of cognitive radio platform, the information of the environment that cognitive radio network needs to know are usage of spectrum.

Network Intelligence

The network intelligence job is collect information the network. The information include network load, traffic, delay information, routing information, network security and network topology. These information about the network status is updated periodically.

User Intelligence

The user intelligence gives information about the needs of users and provider of services to users. This includes user preferences, requirements for improving performance and so on.

Policy Intelligence

The policy intelligence collects information about the rules that are needed for proper operation of cognitive radio network. It also provide security for cognitive radio network operations.

J. Spectrum Adaptive Cluster Architecture

Cluster architecture using the spatial variation of spectrum is proposed in (Mansoor *et al*., 2013). The authors have considered the cluster formation as a bi-clique problem with maximum edge. The clusters are assigned with a free set of channels that are common so as to shift between the control channels. If the CR nodes have common channels and are within the range, they are grouped.

Clustering is one of the simple concepts used to manage ad hoc nodes in large scale. Arranging the network nodes into logical groups to cut the signaling overhead which is essential for network operation and to hold the connectivity to network is a part of Cluster formation strategy. The procedure of grouping nodes is dependent on network characteristics and requirements of the application. For instance, the cluster formation in a dynamic environment needs to be simple and stable. It should be an abstract of the network topology and must be more stable irrespective of the topological and behavioral changes.

Another approach to improve routing and multicasting, is to work on with small number of clusters. The constantly changing behavior of channel using over the brought the researchers to have a keen interest in Cognitive Radio Network (CRN). In (Mansoor *et al*., 2013), the author proposes an adaptive architecture for CRN. The cluster head election is based on a parameter called Cluster Head Determination Factor (CHDF) in the proposed clustering scheme.

In this work, a Spectrum adaptive Cluster architecture is considered for clustering. To decrease the chances of again clustering of mobile nodes, another temporary head of the cluster is created in each cluster that has responsibility to take charge when original one moves out.

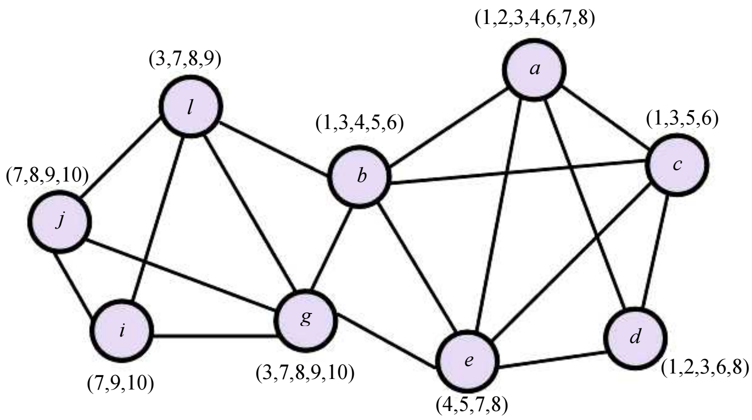
K. Stable Cluster-Based Architecture

In this architecture, the network is divided into group of clusters which take into account the spatial variations of available spectrum. Free common channel is provided for shifting among control channel. Paper states the parameter named Cluster Head Determination Factor (CHDF) for selection of cluster head (Mansoor *et al*., 2014), which coordinates the operation of cluster. Each cluster has a secondary cluster head to compensate the re-clustering of mobile nodes. In cluster based network, nodes are divided into logical groups, where in the geographical area which is same for neighbouring nodes are grouped based on specific criteria. The clustering criteria are based on various factors like network features and application requirements. Clusters in dynamic environment are formed to maintain a stable and simpler network topology. Another objective is to construct lesser number of clusters so as to have a less number of nodes in the network backbone. The components of cluster based architecture are Cluster-Heads (CH), Secondary Cluster Heads (SCH), Cluster Members (CM) and Forwarding Nodes (FN). The paper is based on the consideration that the ad-hoc network is comprised of self-organized Cognitive Radios (CRs) or secondary users (SUs) and SUs have capability to sense and use available free spectrum. The CRs have processing capability to calculate own CHDF value. CRs are also aware of CDHF values of neighbouring nodes.

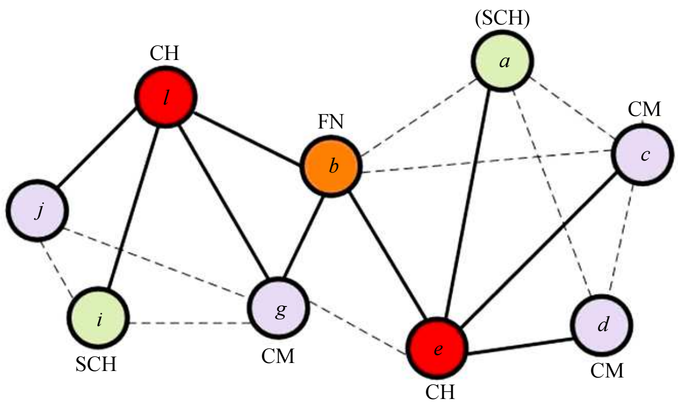
The proposed cluster-based network is presented in Fig. 12b, where solid line represents logical link and dotted line represents physical links. Cluster Head (CH) defines and coordinates operating channels for the cluster. And to find the existence of any other cluster in the neighbourhood, Cluster Member (CM) checks the neighbour list.

L. A Two-level Cluster-based Cognitive Radio Sensor Network Architecture

In this work, an integrated hardware design and software implementation for a Cognitive-Radio Wireless Sensor Network (CR-WSN) is given. The implementation of CR-WSN is an event-driven cluster-based network, whereas the sensor nodes are organized into a two-level hierarchy of clusters, each with its own Cognitive-enabled Cluster-Head (CR-CH) in this network. The information sensed by a sensor node is reported to the associated CR-CH. The CR-CH then transmits the collected information over one of the idle primary radio channels to the data collecting node (sink) based on the chance given.



(a)



(b)

Fig. 12: (a) Connectivity graph of Cognitive Adhoc Network (b) Cluster-based Cognitive Network Architecture

The CR-WSN is categorized as an event detection network in this paper and when an event is detected the collected information is only transmitted to the monitoring centre (sink). The upper level consists of a network of CR-CHs. The lower level of the CRWSN consists of several clusters of sensor nodes, each with its own Cognitive-enabled Cluster-Head (CR-CH). The information collected by a sensor node in a given cluster is sent to its CR-CH over an ISM channel. The CR-CH transmits the real-time gathered information over one of the available PR channels to the sink node based on the chance given.

The CR-WSN is a two-level hierarchical network. The lower level with several clusters, each with a number of sensor nodes. Each cluster monitors a certain area. A network of CR- enabled Cluster Heads (CRCH) forms the upper level. A pre- deployed CR-WSN includes nodes with four different roles. They are the sensor nodes, a CR-CH node, a CR-enabled sink node and a task manager node. The flow of operation of a CR-WSN in a scenario can be explained thus.

The key role of a sensor node in a given cluster is to monitor a given phenomenon in that cluster and to communicate the sensed information to the associated cluster-head in case of event detection. The alarm messages (packets) to the network coordinator are forwarded by Cluster-heads and these messages contain information about the detected events and their locations. The CRCHs can access any of the available (idle) licensed PR channels to relay their data packets to the sink depending upon the chance given. The responsibility of data collection, fusion and transmission to the sink is held by the Cluster-head.

Thus, the monitoring centre is a powerful node that can sense the available spectrum within no time (simultaneously sensing several GHz wide bands) to gather information about the idle channels and it is in the form of a list. Therefore, the channel assignment is done in a centralized fashion based on the priority of the reported events among the cluster heads by the monitoring centre/sink node. In addition, the sink node has a GSM interface to connect to the cellular network/internet. This allows the task manager to take appropriate action based on the messages sent by the sink node. In each cluster the wireless sensor nodes are responsible for monitoring a given situation precisely and the CRN is responsible for efficient forwarding of gathered events to sink node and task manager.

Due to the level based structure of the CRWSN, a hybrid CR-MAC design, called event-driven CR sensor MAC (CRS-MAC) is presented. It divides the MAC-layer functionality into two types: CSMA-based intra-cluster communications and cognitive multi-channel CSMA-based inter-cluster communications.

M. Unified Layered Security Architecture for Cognitive Radio Network

This report details on security architecture of various types of networks and puts forward the unified layered security architecture for the future cognitive radio networks. The layered security architecture consists of two security sub-layers: Security of application layer (sub-layer 1) and physical layer (sub-layer 2). Sub-layer 1 gives importance to the algorithms for encryption, key management, authentication, data encryption and policy strategies. Sub-layer 2 emphasizes on spectrum detection, distribution and recycling. The result of the analysis is the architecture which is adaptable, scalable and suitable for cognitive radio networks as shown in Fig. 13.

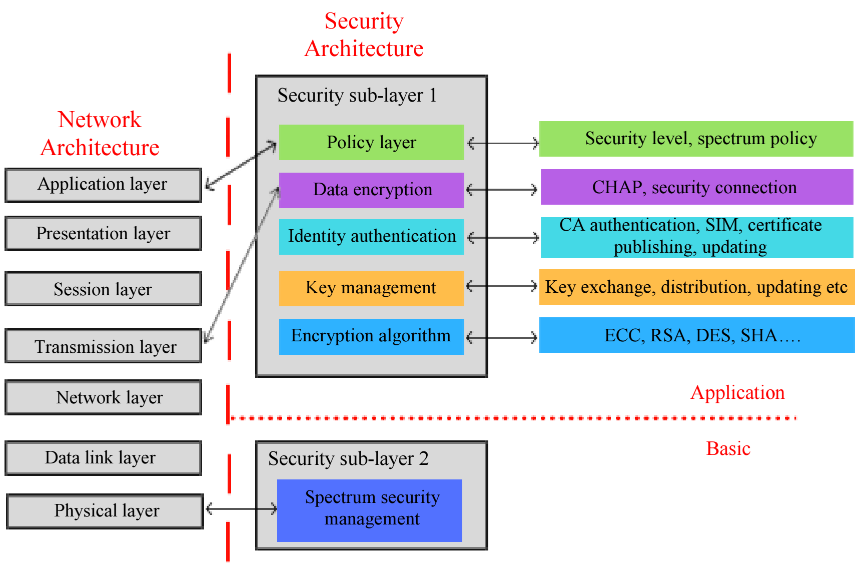


Fig. 13: Security architecture of CRN

The new security architecture has two sub-layers of security. Sub-layer 1's responsibility is for security of network transmission and identity authentication. Sub-layer 2's is to protect security of spectrum.

N. A Cross-Layer Architecture of CRN for Cognitive Mesh Networks

Urban-X, a first step to a new architecture for Cognitive Networks which in the form of Mesh architecture. Novel methods for transfer of data shows the transfer of outer nodes are designed depending on a scheme called cross-layer scheme. Authors propose a new architecture consists cognitive mesh nodes which performs sensing of channel and transfer of data based on sensing. In contrast to normal cognitive radio network, the cognitive mesh architecture does not need to evacuate from when it senses another device using the same spectrum. The spectrum sensing is basis to evaluate the work load of primary channel. It also helps to evaluate the operation of least used channel. The back bone network is self-organisable and frequently changing based of network load and mesh networks load.

Urban-X includes both clients from mesh network and cognitive mesh network nodes along with primary user network. The primary network can use access point and also Bluetooth devices. The mesh network contains multiple Wi-Fi radio interfaces.

The Urban-X source node sends Route request to all the nodes in the network through the coordinator node. The nodes who gets the request broadcast it to other nodes. Unlike other routing protocols like AODV, the intermediate nodes can again broadcast duplicate route request to other nodes. After receiving the broadcasted request, the destination node reply with message which is send only to source node.

Implementation

Network Simulator-3(ns-3) was used as the simulation platform with C++ as coding language.ns-3 is mainly used on Linux systems and several external animators, data analysis and visualization tools can be used with it as shown in Fig. 14. NetAnim is used for network animation purpose. Microsoft excel is used for representation of simulation result in the graph.

A. Simulation of Cognitive Radio Network Architecture based on Clustering in Adhoc Mode

In this paper, implementation of algorithm is done to form clusters in ns-3 environment. The cluster in the architecture is composed of are Cluster Heads, Cluster Members and cluster base station. Distance, time of nodes in the cluster are taken as the input for clustering algorithm.

The criterion for cluster formation is based on time period nodes are expected to lie on communication range. The description of algorithm for implementing the cluster based cognitive radio network is done in this section.

Clusters are formed based the distance, time to which nodes remain in the cluster. The cluster head selected based on the number of neighbouring nodes whose average velocity and distance is similar. Figure 15 and 16 shows the Simulation of Cognitive Radio Network architecture based on clustering in Adhoc mode in ns-3.

B. Algorithm Description for Cluster Formation and Cluster Stability

The speed (velocity) variation among neighboring nodes is the key feature to construct stable clusters. Neighboring nodes are defined as stable or unstable clustering neighbours based on their velocity vector and only neighbours that are stable may form clusters. In addition, any two nodes could be divided into d-Stable and 2d-Stable according to their d distance. The architecture is designed to focus on longer cluster lifetime where participating nodes calculate their average velocity and through message broadcasting all nodes receive the values of the neighbouring nodes. Another goal of clustering is to create cluster with backbone network less. This will improve or increase the efficiency in routing and multicasting.

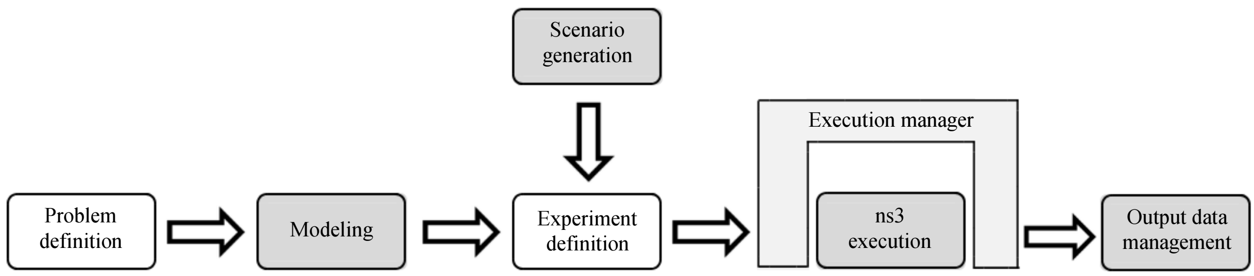


Fig. 14: ns-3 overview

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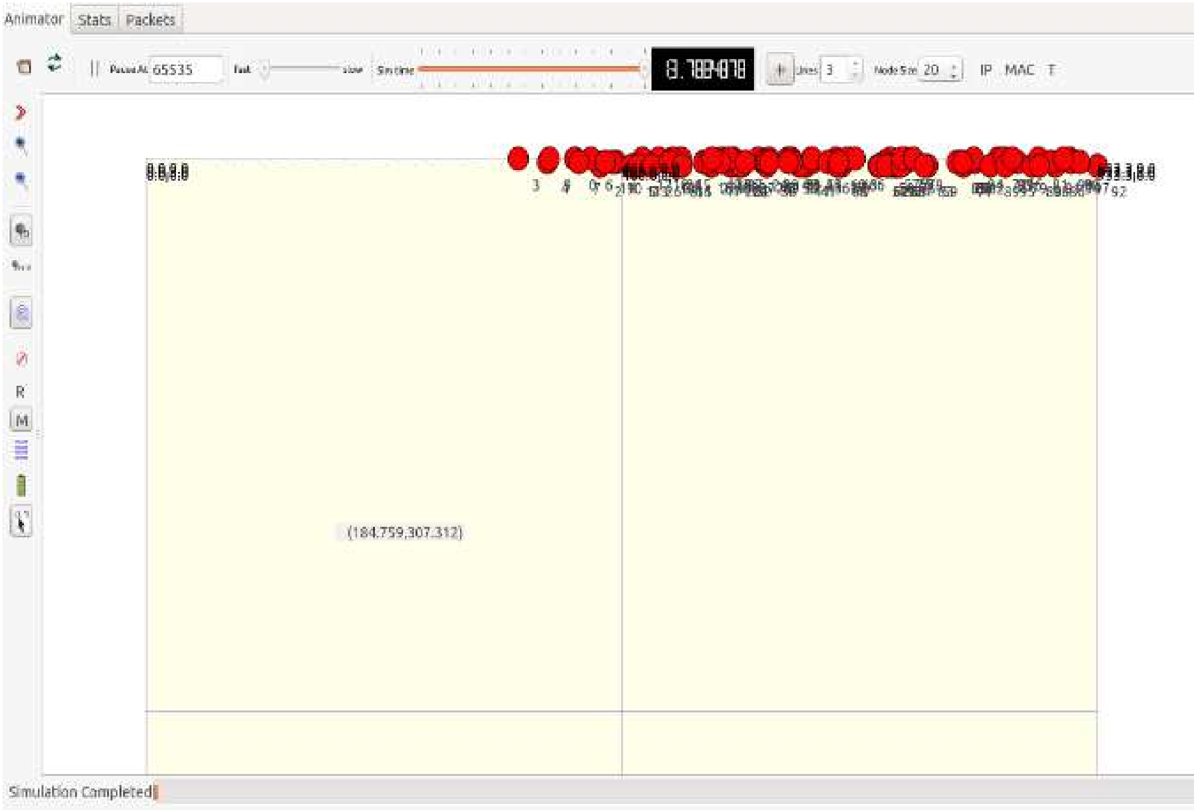


Fig. 15: Simulation of cognitive radio network architecture based on clustering in adhoc mode

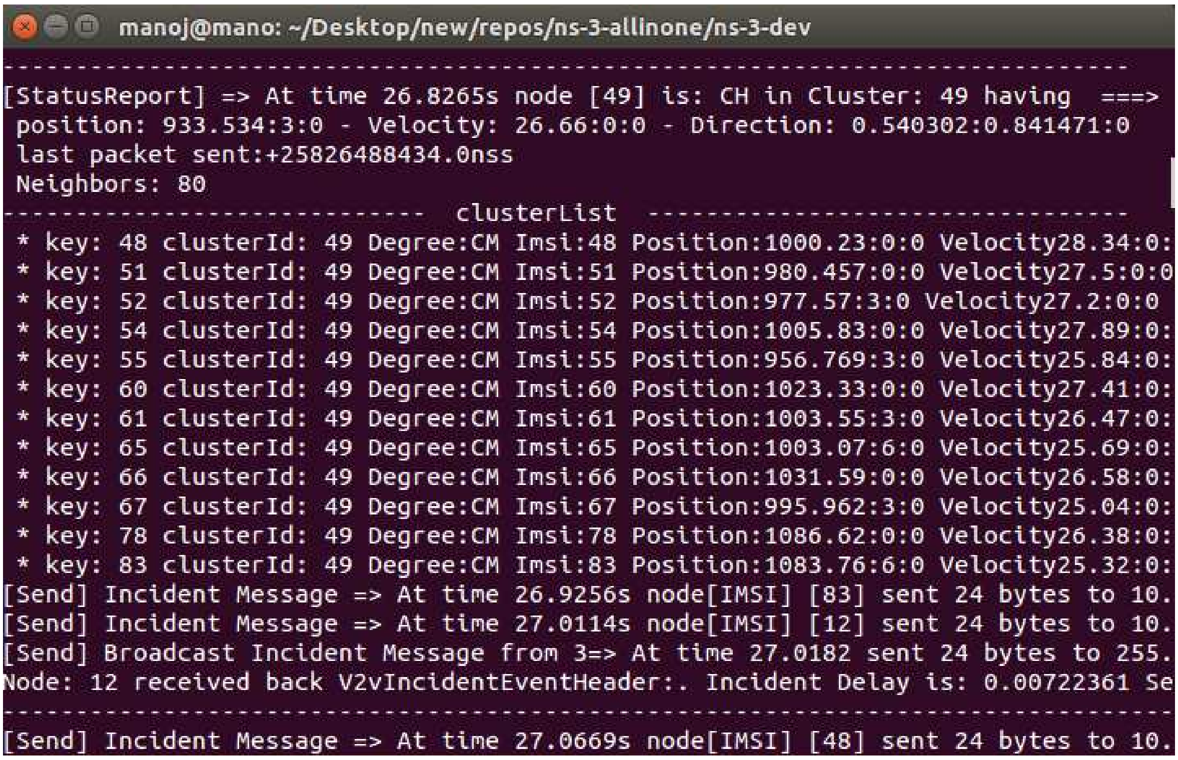


Fig. 16: Cluster formation information with Cluster Head (CH), cluster id, position and velocity

The nodes broadcast their current mobility state by sending messages. Neighbours with average velocity less than a predefined limit will be considered as stable neighbours. The cluster formation starts when slowest node sends cluster-originating message. On receiving this message 2d-stable neighbours with greater speed changes cluster Identifier (ID) temporality to the ID of starting node and calculate their appropriate value to become Head of the cluster.

Suitability to find the node value is proportional to the variation of its position and velocity compared to the average values calculated by the node's stable neighbours. This value how time node has wait to inform its capability to become the head of cluster and send message to create a new cluster. Nodes which receive the message from another node to form a new cluster come out of the cluster head election and changes its id same as the cluster head member. All nodes follow the same procedure to form remaining clusters.

Joining a Cluster

This process can be divided into two stages. If there is only one Cluster Head (CH) in the reachable area then a potential CH will accept the node in case their speed deviation is lower than a predefined limit. If there are more one node which can become head of the cluster, then nodes forms the cluster based how much time it will remain in the same cluster. This is calculated based on speed, direction and position information that nodes already have for their neighbours.

Leaving a Cluster

If there is no Cluster-Head (CH) in the reachable area to attach and no independent nodes to form new cluster, then the nodes changes its state to independent and leaves the cluster.

Cluster Merging

When two heads of clusters are the in same range and their velocity variation is near a specific range then a cluster merge event may be initiated. Head of cluster with low members should come out of CH role. Cluster head with low neighbours seize to become cluster head and becomes member in the other cluster. New members can join when they share the same range as that cluster head. Independent nodes can initiate a new election and create new cluster.

C. Evaluation and Performance Analysis of Clustering Architecture

In the simulation using ns-3, clusters number increase when number of nodes increases Fig. 17. In a network of 100 nodes, 5 clusters are created in the Cognitive Radio Network architecture based on clustering in Adhoc mode implemented as part of the paper. By increasing the number of nodes to 500, 15 clusters are formed.

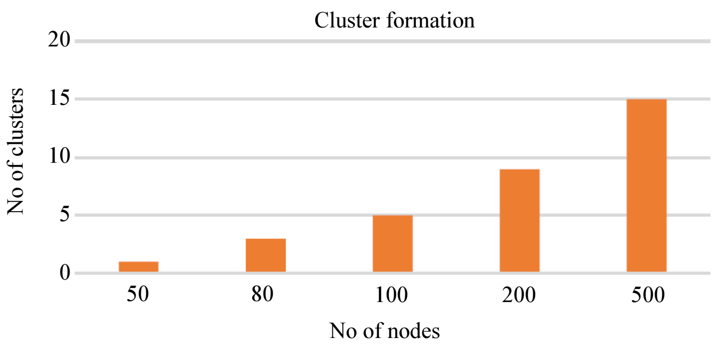
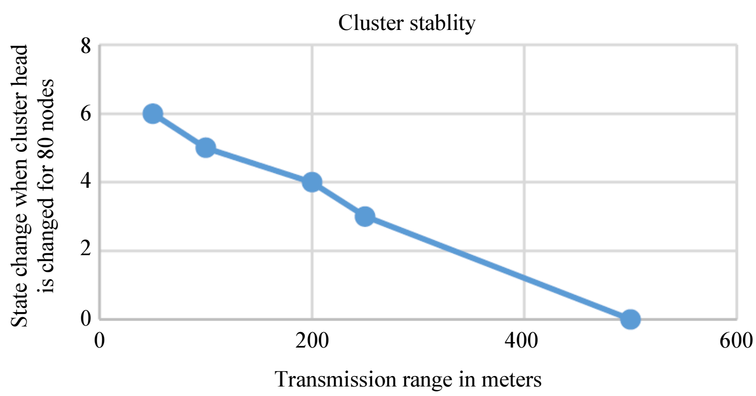


Fig. 17: Cluster formation



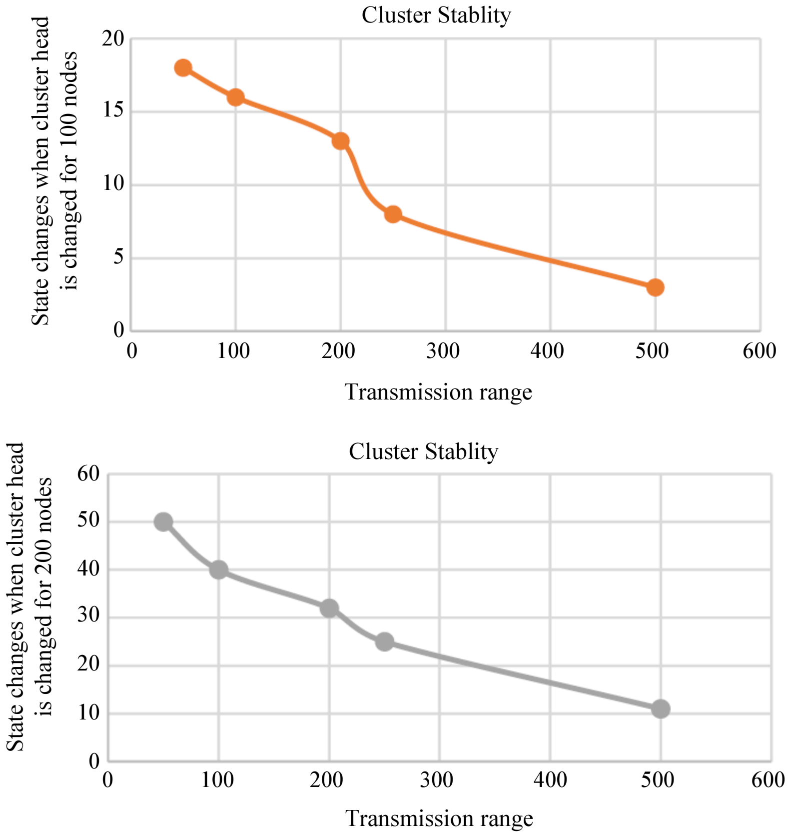


Fig. 18: Cluster stability status

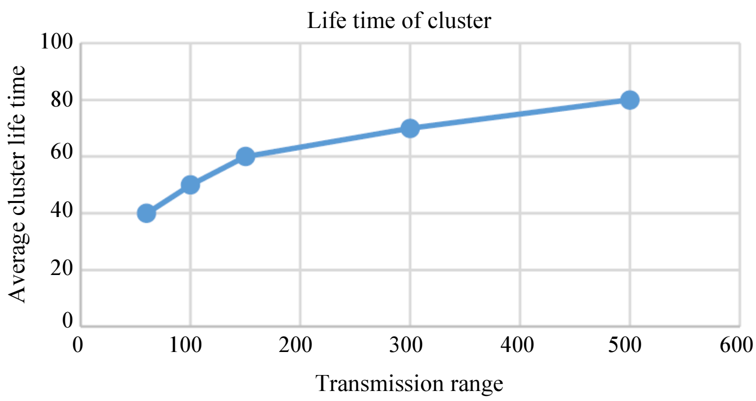


Fig. 19: Average cluster life time for 100 nodes

Stability of the Cluster

Clustering should remain stable even though nodes are mobile. A good algorithm's goal should be to minimize the changes in cluster by minimizing the change of nodes between various clusters. The following events (or state changes) are considered in this paper:

- *State 1:* Cognitive node or cluster head come out of the current cluster creating a new one
- *State 2:* Cognitive node come out of the current cluster and enters a neighbouring one
- *State 3:* Head of the cluster shifts to the neighbouring one

The stability of cluster when cluster head changes as cluster head comes out cluster and creates a new for 80,100 and 200 nodes by varying the transmission range in meters are given in Fig. 18.

Cluster Lifetime

The cluster lifetime is critical measurement that denotes the clustering algorithms improved performance. It is proportional to the how long head of the cluster same in the cluster as shown in Fig. 19.

Conclusion

This paper investigates the various architectures of Cognitive radio network such as cluster based architectures, self-organize network architecture, policy based architectures, layered architecture and architecture for the heterogeneous networks. Further the paper explores the relationship between the nodes and cluster formed, the stability of the clustering based on the parameters time, distance and cluster life time. For better understanding purpose, ns-3 simulation tool has been used to develop scenarios with different conditions and checked for analysis purpose.

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Author's Contributions

Manoj Ramachandran: Has done the idea formation, literature survey, plan development, implementation and analysis.

Harish Sheeranalli Venkatarama: Being the mentor for the research has helped in idea formation, research planning and overall supervision.

Sandesh Hebbar: Has prepared the abstract and summary, helped in methodology formulation and in formatting the paper.

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