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Cooperative Communication with Uplink Power Control and Cognitive Radio using TV Whitespace Network in Cellular Networks

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Abstract— In a multi user environment, a number of users share the same radio resources. A consequence of the limited availability of radio channels in the network is that the same channel has to be assigned to many users. Thus a signal intended for a certain user will reach other users and introduce interference to their connection, and degrade the quality. Uplink power control is a key radio resource management function. It is typically used to maximize the power of the desired received signals while limiting the generated inter-cell interference. This paper explores a decentralized uplink control algorithm for the users who experience a low signal and call drops stuck in a traffic condition especially in a jam taking into consideration the huge load future cellular networks will encounter. The paper further analyses and explores ways for enhancement and the capability of cellular networks to accommodate the increasing number of networked devices, as we need a rapidly expanding network with optimum utilization of resources. Cognitive radio network is the latest attempt towards achieving this goal. The paper will also explore different techniques to exploit underutilized TV whitespace spectrum for better Quality of Services (QoS) and serving increased number of people especially when a user in a highly congested traffic area moves to a high way area and experiences low signals especially considering the Indian road conditions

Index Terms— LTE Advanced; Cognitive Radio (CR); Coordinated Multipoint Transmission/Reception (DL/UL CoMP), TV Whitespacing (TVWS), Clique; Genetic Algorithm

1 Introduction

In LTE, the standardized uplink (UL) power control formula contains an open loop component and a closed loop component. In open loop power control (OLPC), the transmitting power is set at the user equipment (UE) using parameters and measures obtained from signals sent by the base station. In this case no feedback is sent to the UE regarding the power to be used for transmission. The open loop part of the scheme is often called Fractional Power Control (FPC) because it allows User Equipments (UE) to partially compensate the path-loss. FPC is characterized by two main parameters: a target received power P0 and a compensation factor α. The closed loop component is considered to improve the performance of FPC by compensating fast variations in channel. In closed loop power control (CLPC) the base station sends feedback to the UE, which is then used to correct the transmitting power. Qualifying the power control technique as open loop and closed loop helps to have an anticipated idea of the implementation complexity and expected level of performance. For example, it is presumed that a closed loop power control scheme would require high signal overhead of transmission but at the same time it would provide with a fast mechanism to compensate for interference and channel conditions. On the other hand, an open loop power control would result in simpler implementation and low signalling but would be unable to compensate for channel variations for individual users. *Graph theory* is attracting researchers worldwide to use them for network planning and optimization schemes. In this paper, the authors have tried to develop a new uplink power control algorithm for the LTE users stuck in traffic. The algorithm uses *clique* concept borrowed from graph theory. A detailed overview of the algorithm and its implications has been taken into consideration.

As reported for the year 2015 there is a 21% growth in active internet users, nearing 3 billion were in November 2014. There is a 12% increase in the social media accounts worldwide. Addition of 185 million unique mobile users and a record 23% hike in mobile social accounts. These statistics clearly reveal the penetration of network in daily lives of general global population and it shows no signs of slowing down. In addition, our day-to-day utility items such as remotes, microwaves etc. also make use of the spectrum for communication and operation. Hence, we need a scalable, rapidly expanding framework which is able to keep pace with the growth. Specifications for Long Term Evolution (LTE) are being developed for a long time now. Till now, the *spectrum usage is divided in two bands, licensed band and unlicensed band*. *Licensed band* is available to select users at a cost, offers better QoS compared to unlicensed band but remains largely underutilized. On the other hand, *unlicensed band* despite offering comparatively low SNR, range, bandwidth, reliability attracts huge numbers of users because of no cost and freedom to develop and innovate. This causes lot of interference in the unlicensed band. To fully utilize the scarce spectrum, LTE is being developed. *One possible avenue in LTE is exploitation of TV whitespaces*– parts of TV spectrum which are unutilized in a geographical area – for deployment of femtocells/small cells, providing better coverage and QoS. The authors have also made an attempt to develop a technique for the same by borrowing principles from *genetic algorithm*.

The study on *Genetic Algorithm and Clique based Uplink Power Control algorithm* is a theoretical analysis and determines cooperative communication to offer best QoS and throughput to the LTE users.

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2 Related Work

2.1 Coordinated Multipoint (CoMP) Field Trials and implications

*Coordinated Multipoint: Concepts, Performance, and Field Trial Results_* has shown that coordination of cells in wide-area systems is not only beneficial for average spectral efficiency and cell edge data rates, but can also be implemented. *CoMP* was demonstrated for uplink and downlink in two test beds in urban areas. *CoMP* schemes for the uplink (UL) range from joint multicell scheduling to more complex joint detection, and can be centralized or decentralized. In the downlink (DL) the schemes range from less complex coordinated scheduling to more challenging joint processing approaches. From the technical as well as economic points of view, intrasite cooperation will be much easier to realize. However, intersite cooperation will be needed in order to exhaust the full interference reduction potential of base station cooperation. The combination of joint processing at one site with joint scheduling between the sites is of great interest as it provides promising gains with limited backhaul.

Let us consider a mobile subscriber in India moving away from a city and travel across in a National Highway, in this case the UL CoMP can offer various challenges which includes:

- *MU-MIMO technique:* Includes uplink Interference Prediction and Joint Detection Processing for optimum performance in the UL.
- *Other challenges include:*
  1. *Clustering:* Suitable clusters of cooperating base stations have to be found, which can be done in a static way or dynamically
  2. *Synchronization:* Cooperating base stations have to be synchronized in frequency such that intercarrier interference is avoided, and in time in order to avoid both intersymbol and intercarrier interference. The maximum distance of cooperating base stations is limited since different propagation delays of different terminals may conflict with the guard interval. While concept of complex equalization is there
  3. *Channel estimation*: A large number of enodeBs (eNBs) in the CoMP cluster in the UL will require a larger number of orthogonal UL pilot sequences. At some cluster sizes, the *CoMP* gains are outweighed by capacity losses due to additional pilot effort.
  4. *Complexity*: Here for UL with the Home eNode Bs(HeNBs) single-carrier (SC)-FDMA is used what is the impact of data performance
  5. *Backhaul:* We may need Adaptive decentralised/centralized cooperation.
  6. Non- contiguous Carrier Aggregation with inter band cells and with Technologies like TVWS

The concepts of *Clique* and *Genetic Algorithm* mentioned below may assist in overcoming these challenges and theoretically analyses the simplistic approach for offering good throughput and better QoS for LTE users in their network

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2.2 Developing Case Study for Decentralised Clique based Uplink Power Control Algorithm

In recent times, G*raph theory* has attracted researchers from cellular industry and has been implemented in many applications. The reason for its popularity is its similarity with the scenarios in the cellular network. The authors figured out a widely used graph theory concept known as *Clique* to be pretty much applicable to our problem statement for people stuck in traffic condition and needing better uplink throughput. A *clique* is subset of vertices of an undirected graph, such that its induced sub graph is complete; that is, every two distinct vertices in the clique are adjacent. *Cliques a*re one of the basic concepts of graph theory and are used in many other mathematical problems and constructions on graphs. Sub graph of a graph with the most vertices that are mutually connected in the compatibility graph is defined as a maximum clique in graph theory. The maximum clique can be obtained by determining the largest cardinality (i.e., size) of all the maximal cliques of the compatibility graph, where a maximal clique defines a clique that cannot be enlarged. The task of finding whether there is a clique of a given size in a graph (the clique problem) is NP-complete, but despite this hardness result, many algorithms for finding cliques have been studied. In many cases a graph has more than one maximum clique. For a graph *G*, the size of a maximum clique in *G* is called the clique number of *G*, written $\omega(G)$. Futher analysis was carried out by the authors related to about clique and its usage in the cellular networks domain. Two of such implementations are:

i. *On-Line Small Cell Access Structure Planning-* In this scenario, small cell antennas are installed to cover high-demand areas while a number of small cell BSs are distributed across the operators' network. The BSs are the signal processing boards in base station racks, processing the digital signals of small cells. The concept of a clique in graph theory can be exploited to determine the best pairing of small cell antennas and BSs – given changes in geographical distribution and traffic demand in coverage areas. To achieve this, a compatibility graph of the small cell antennas is first generated to graphically describe the interference tolerance between the cells. Here, a vertex represents an antenna, and an edge connecting two vertices represents that

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the interference between the two associated small cells is tolerable. Frequencies are allocated to the maximum cliques of the graph, until traffic demands of all the small cells are satisfied. Next, we can generate another, new, compatibility graph to characterize the constraint of connecting multiple small cell antennas towards a single BS. In this graph, each vertex *indicates* a small cell antenna, and two vertices are connected with an edge if the two corresponding small cell antennas are allocated with non-overlapping frequency bands. The BSs are then paired with the maximum cliques of the graph one by one, until no antenna is unconnected. By doing this, every BS is most efficiently used, processing the largest amount of traffic load it can. Also, the small cell antennas are all best satisfied with their allocated frequency bandwidths, as none of them is compromised by reducing their allocated bandwidths. In the case where there are not enough BSs to connect the small cell antennas, a convex quadratic minimization problem can be formulated to let the unconnected small cell antennas share the frequencies with already connected small cell antennas, hence connecting to their BSs. The frequency shares of the small cell antennas are optimized, so that the satisfaction degradation of all the cells is minimized.

ii. *Small Cell Microwave Backhaul Configuration-* Frequency division duplex (FDD) is considered on each backhaul link. Therefore, two frequency bands are required. On the point-to-point backhaul links, every backhaul antenna transmits in one band, and receives in the other. Adjacent backhaul antennas along a backhaul branch exploit the two bands in an alternating manner, so that the backhaul can be scaled up to multiple hops. Small cell traffic travels along the backhaul links to and from the gateways, where the core network is connected. In this application, the use of clique in graph theory can be extended to capture the drastically varying traffic on the backhaul links, allocate bandwidths, and avoid collisions between the links with co-located receivers. The clique idea can also be extended to decide the best backhaul paths for the small cells, so that the traffic can be evenly distributed across the backhaul networks, eliminating bottlenecks. The clique idea can further be extended to arrange guard bands, which are crucial to mitigate excessive adjacent-frequency interference (between co-located receivers) resulting from inaccurate synchronization of practical backhaul links. These enable the backhaul routes to be adaptively configured, hence relieving a critical problem of backhaul congestion.

While studying these applications the authors figured out that decentralization of the macrocell would be a better option for our case study because a number of users can be scheduled within milliseconds to transmit/receive with different powers at different locations of every cell. Interference changes frequently. Power control at short intervals of milliseconds is critical, which cannot be effectively addressed using a centralized approach. The users were divided into two categories on the basis of their SINR values and treat them differently when stuck in traffic as: *1) Within Small Cell Users ,2) Small Cell Edge Users*. For the within small area users clique algorithm will be used for optimal power control in the uplink and for the cell edge users coordinated multipoint algorithms will be used.

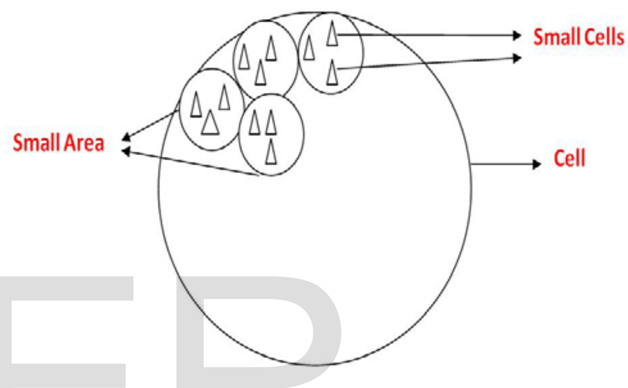

Fig. 1 Decentralized Approach

To create an Uplink power control algorithm in LTE for ***within small area users*** following are the details:

a. Create a compatibility graph of each small area.
b. Find different cliques possible for each such graph.
c. Allocate a fixed power P_i for every clique i according to the parameter set PS.
d. Repeat steps a to c after every t time.

Note: We need to perform iterations to find new cliques and fixed power parameter associated with them for the following reasons:

a. We need to balance the load of the traffic on the small cells.
b. The small cells which are not interfering currently may interfere at some other time so the algorithm should be adaptive enough to accommodate the changes in the network and network conditions.

Feasibility of the Clique Algorithm

The clique concept has been widely used in various other cellular networks problems like network planning, resource allocation, microwave backhaul configuration, etc. The simulations results have shown that the clique concept is applicable and shows positive results. However, as users move to the no small cell zone especially as we move to highway or non-uniform deployment of small cells sensing unlicensed spectrum or TVWS spectrum will be required to maintain the spectrum efficiency and throughput which is best explained in the section below using Cooperative Communication with TVWS.

2.3 Developing Case Study for TVWS Spectrum using Genetic Algorithm

For the successful usage of TVWS, we identify detection presence of Primary users and a spectrum hole as a major challenge. Various techniques have been employed to this such as *(i) Matching Filters,(ii)Cyclostationary Feature Detectors,(iii) Covariance based Sensing*. But all the techniques mentioned above require some predetermined and/or accurate features of signals and channels. This led to development of Energy Detection. Advantages of using Energy Detection are as follows: *(i)* Low computational complexity, *(ii)* Applicable to any signal shape,*(iii)* No a priori knowledge of PU and their transmission required. But the implementation has several drawbacks, such as *:(i)* It is not easy to set the threshold values, *(ii)* It takes time to average,*(iii)* It does not distinguish interference from signal and noise. To overcome these drawbacks, a combination of *Hidden Markov Model (HMM) and Quickest Detection for Cognitive Radio* was introduced. The technique uses continuous sweeping of Frequency Spectrum and the results are output quickly. The output also includes the starting point and end point of usable spectrum. This reduces the delay between the spectrum output and spectrum sampling.

But the problem in application of HMM model lies with conventional HMM recognition using Viterbi Algorithm. Because when the spectrum is swept, exact starting points and ending points of spectrum segments are hard to be determined. Thus errors will accumulate outside of the range of the spectrum segments, which affects the final decision of recognition. In addition, for Viterbi algorithm, the presence of recognized spectrum segment will not be announced until the whole spectrum segment is swept, which introduces much time delay for spectrum detection. Thus, we plan to explore *genetic algorithm* as a viable alternative for efficient spectrum detection.

Genetic Algorithms (GAs) are adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. As such they represent an intelligent exploitation of a random search used to solve optimization problems. Although randomized, GAs are by no means random, instead they exploit historical information to direct the search into the region of better performance within the search space. The basic techniques of the GAs are designed to simulate processes in natural systems necessary for evolution. It is better than conventional AI in that it is more robust. Unlike older AI systems, they do not break easily even if the inputs changed slightly, or in the presence of reasonable noise. Also, in searching a large state-space, multi-modal state-space, or n dimensional surface, a genetic algorithm may offer significant benefits over more typical search of optimization techniques. GAs simulates the survival of the fittest among individuals over consecutive generation for solving a problem. Each generation consists of a population of character strings that are analogous to the chromosome that we see in our DNA. Each individual represents a point in a search space and a possible solution. The individuals in the population are then made to go through a process of evolution.

A population of individuals is maintained within search space for a GA, each representing a possible solution to a given problem. Each individual is coded as a finite length vector of components, or variables, in terms of some alphabet, usually the binary alphabet {0, 1}. To continue the genetic analogy these individuals are likened to chromosomes and the variables are analogous to genes. Thus a chromosome (solution) is composed of several genes (variables). A fitness score is assigned to each solution representing the abilities of an individual to `compete'. The individual with the optimal (or generally near optimal) fitness score is sought. The GA aims to use selective `breeding' of the solutions to produce `offspring' better than the parents by combining information from the chromosomes. The GA maintains a population of n chromosomes (solutions) with associated fitness values. Parents are selected to mate, on the basis of their fitness, producing offspring via a reproductive plan. Consequently highly fit solutions are given more opportunities to reproduce, so that offspring inherit characteristics from each parent. As parents mate and produce offspring, room must be made for the new arrivals since the population is kept at a static size. Individuals in the population die and are replaced by the new solutions, eventually creating a new generation once all mating opportunities in the old population have been exhausted. In this way it is hoped that over successive generations better solutions will thrive while the least fit solutions die out. New generations of solutions are produced containing, on average, more good genes than a typical solution in a previous generation. Each successive generation will contain more good `partial solutions' than previous generations. Eventually, once the population has converged and is not producing offspring noticeably different from those in previous generations, the algorithm itself is said to have converged to a set of solutions to the problem at hand.

Implementation of Genetic Algorithm

Based on Natural Selection after an initial population is randomly generated, the algorithm evolves the through three Operators:

a. Selection which equates to survival of the fittest;
b. Crossover which represents mating between individuals;
c. Mutation which introduces random modifications.

a. *Selection Operator*

- Key idea: give preference to better individuals, allowing them to pass on their genes to the next generation.
- The goodness of each individual depends on its fitness.
- Fitness may be determined by an objective function or by a subjective judgment.

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b. Crossover Operator

- Prime distinguished factor of GA from other optimization techniques
- Two individuals are chosen from the population using the selection operator
- A crossover site along the bit strings is randomly chosen
- The values of the two strings are exchanged up to this point
- If S1=000000 and s2=111111 and the crossover point is then S1'=110000 and s2'=001111
- The two new offspring created from this mating are put into the next generation of the population
- By recombining portions of good individuals, this process is likely to create even better individuals

c. Mutation Operator

- With some low probability, a portion of the new individuals will have some of their bits flipped.
- Its purpose is to maintain diversity within the population and inhibit premature convergence.
- Mutation alone induces a random walk through the search space
- Mutation and selection (without crossover) create a parallel, noise-tolerant, hill-climbing algorithms

Effects of Genetic Operators

- Using selection alone will tend to fill the population with copies of the best individual from the population
- Using selection and crossover operators will tend to cause the algorithms to converge on a good but sub-optimal solution
- Using mutation alone induces a random walk through the search space.
- Using selection and mutation creates a parallel, noise-tolerant, hill climbing algorithm

Fitness Function

It is used by the selection operator to select the initial population from the search space. For our case study for the highway, we identify different parameters to be possible candidates for fitness function of TVWS, such as:

- *SNR Target:* It identifies the maximum number of users a channel can accommodate without causing interference.
- *CQI:* Channel Quality Indicator is reported by UE to eNB. It is used to predict the downlink channel condition. Higher the value of CQI reported by UE, Higher the modulation scheme and coding rate is used by eNB to achieve higher efficiency.
- *KPI:* The key performance indicators can be kept in mind to modify the fitness function accordingly.
- *Modulation Scheme:* Depending on the channel quality, modulation schemes can be altered for most efficient transmission, such as, at higher CQI values, QPSK and QAM-64 can be used.
- Jitter: It can be used to identify the delay in the network and hence make suitable adjustments to frequency and power.
- Primary user Vs Secondary User: Primary user has to be given preference over secondary user. Thus, we can iteratively find the acceptable number of secondary users in a channel which do not interfere with the primary users. High number of primary users in a channel will prevent its allocation to secondary user. Also, a high number of secondary users should be avoided as much as possible to allow the primary user to access the resource at will. Too many secondary users might consume all the radio resources leading to blocking of primary users. Preemption of resources from secondary users will degrade the quality of service offered. Hence, a suitable mix of primary and secondary users is required. The aim is to identify the combination of parameters which will provide a robust, optimum solution without requiring too much computational time. The proposed solutions for spectrum detection take a lot of time, requires lots of precomputation channel related data which is not always available or prone to changes. They are prone to errors and generally face difficulty in distinguishing Signal from Noise. By using the genetic algorithm, it is proposed to define a Fitness Function based on above mentioned parameters and randomly select the channels from the available spectrum. The selected spectrum are then aggregated and compared for their user handling capacity, resultant bandwidth, interference levels etc. Mutation operator is applied to identify a more robust channel pair than the result of crossover operator. The genetic algorithm is iterative and robust, mostly tolerant to altering inputs and noise. After multiple iterations, the model is expected to yield best channels to accommodate the users. It will depend on the parameter chosen for fitness function and their threshold values. The algorithm also needs to be run regularly to accommodate the changes in network and continuously produce best results. Crossover operator in the stage of infancy aggregates only two channels. But, it can aggregate more than two channels together. To obtain best results, optimization of crossover operator is also needed. It needs to be able to intelligently choose the number of channels to be aggregated based on different conditions such as interference, number of active users and number of primary users in a channel at any given time, etc.

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3 CONCLUSIONS AND DISCUSSIONS

The authors were able to successfully develop a decentralised clique based- decentralised solution for uplink control power for LTE users stuck in a traffic jam giving them performance better than the conventional uplink control power algorithm. Clique uplink control algorithm can be a feasible solution for uniformly distributed small cells in a small area with people stuck in traffic jam. As the users move towards cell edge CoMP techniques will help them maintain the required UL throughput. As the user moves to the no small cell zone the TVWS spectrum can be best utilized for giving the required throughput to the user travelling in a Highway. The authors chose genetic algorithm and have proposed different parameters for the fitness function. Given that algorithms like Genetic Algorithm, Machine Learning etc. have found their application in variety of fields, they present an obvious choice for the dynamic and robust algorithms. Carrier Aggregation of licensed and unlicensed spectrum: With the aggregation of unlicensed spectrum used in small cells and licensed spectrum acting as the core network, it is possible to maintain seamless mobility and enhance the quality of service. It will provide higher bandwidth, better penetration. The system can be built as an extension of existing LTE network without requiring any separate resources. The feasibility of decentralised Clique concepts and Genetic Algorithm can further be verified with various field trials.

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