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A Systemic Review of Interference Reduction and Management Techniques in Cellular Network

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Abstract. The increase of interference in cellular network makes the development of efficient interference management techniques a key enabler. But, as we move towards denser networks, interference management is becoming increasingly challenging. In modern times, communications technologies serve as the driver of social, economic and political developments. But, interference in the communication networks comes as undesirable nuisance. In this paper, techniques employed in the management of interference encountered in cellular networks are reviewed systemically. Propositions by different authors including intermodulation solutions, frequency planning methods, genetic algorithms, simulated annealing models, ant colony and multi-agent optimization, artificial neural networks model and evolutionary strategy approach (EAs), are X-rayed. Despite all efforts, challenges of interference still abound in communication networks. Among several techniques available to address interference networks, EAs has been given wider applications and the result shows good performance of the technique. Meanwhile, genetic algorithm is also efficient where applied, but to reduce interference to the minimum in the current and future cellular networks, this paper proposes synchronization of reduction techniques, where traffic-driven factors are considered.

Key Words: Cellular, Communication, Management, Networks, Optimization

Introduction

The most common example of a cellular network is a mobile phone network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station) or transmitting tower. Radio waves are used to transfer signals to and from the cell phone. A radio wave is an electromagnetic wave which emanates from a radiating source. The radio wave assumes all the properties of a plane wave; the wave-front is the plane which contains the Electric (E) and Magnetic (H) vectors and is at right angle to the direction of propagation and power flow. Usually, it is convenient to carry out studies in terms of the electric component, E of the wave which is known as the electric field strength of the radio wave (Bakare *et al.*, 2019). Modern mobile phone networks use cells because radio frequencies are limited and shared resource. Cell-sites and handsets change frequency under computer control and use low power transmitters so that the usually limited number of radio frequencies can be simultaneously used by many callers with less interference. Over the last decade, cellular communications have been one of the technologies that grows rapidly. It is evidently reflected by the high demands of user for new connections and services in terms of quality and capacity of the networks.

Managing interference from other users sharing the same frequency bands has been the key driver for this paper. Interference can simply be defined in wireless communication as an unwanted signal that corrupt the desired signal, thereby reducing the quality of the desired signal. They operate in the same frequency band and share similar structure and characteristics, hence always difficult to terminate. In contrast, interference can be distinguished from thermal noise in its physical statistical features, because thermal Noise is normally distributed, whereas interference has the same structure as the desired signal. It is good to note that interference is desired signals in other systems and for other users (Bakare & Idigo, 2019). Interference management can be described as a technique or process employed for the control and mitigation of interference. It can be further described as a scheme for interference cancellation, avoidance, or reduction in a system. Mitigation techniques are required either to further reduce the risk of interference or to solve the possible interference cases which would occur despite the application of the general measures in terms of out-of-band emission limitations (Bakare *et al.*, 2021)

The first wireless phone systems served as extensions to the wired public switched telephone network. These systems were "single cell" systems in the sense that mobile terminals could be connected to only one base station during a call, with the call being lost when out of range of the base station, akin to losing an FM radio signal while driving out of range of the station. Interference in these networks could be managed by simply orthogonalizing the users in the time–frequency plane, i.e., through the use of time-division multiple-access (TDMA) or frequency-division multiple-access (FDMA), or some combination of the two. Interference between base stations operating in the same frequency band was managed by ensuring that they are geographically far apart, again akin to the way in which radio stations operating in the same frequency band are placed (Venugopal, 2018). This paper seeks to review the interference mitigation techniques of cellular network.

Review of Related Works

Several authors have addressed the problems of interference management in the cellular networks. These authors proposed several techniques with the aim of addressing various aspects of interference. For example, Brehmer and Utschick (2010), Adediran *et al*. (2017) propose weak cooperation as an interference management technique among BS in order to gain significant performance. Evolutionary strategy approach was employed by Vidyarthi *et al.* (2005) to address the challenges in channels allocation aimed at minimizing the problems of interference, which can manifest as call blocking or dropping. Dorne *et al.* (1995) also employed evolutionary approach for the frequency assignment problem with the aim of minimizing interference in cellular network. The authors designed a hydrid EAs integrating local search, constraint programming, etc. into evolutionary operators, which was shown to speed up performance.

Oguejiofor *et al*. (2018) also reported that as we evolve towards 5G networks, achieving spectral efficiency and energy efficiency and dealing with interference are among the greatest challenges encountered so far. They addressed interference issues and its causes in Heterogeneous Cellular Networks (HetNets) and how they have been combated using different management techniques. They revealed that most of these interference management techniques, when applied to HetNets, do improve the performance of HetNets, but could not mitigate dominant interference scenarios in HetNets when frequency reuse-one deployment is employed. Jänis (2013) showed that interference management is needed in order to facilitate reliable and efficient shared band operation. For this purpose, three methods are proposed that provide interference aware power control, interference aware multiuser and multiband resource allocation, and interference avoiding spatial precoding. It is shown that enabling direct transmission itself provides most of the gains in system capacity, while the interference management schemes are more important in promoting fairness and reliability.

Despite the above, challenges of interference still abound in communications network. In this paper, efforts are made to review interference management techniques that are available in open literature. This paper presents these techniques in logical manner with a view to identifying the strengths and weaknesses in each approach.

Cellular Concept

A major breakthrough toward improving both the capacity and the mobility in wireless phone systems came with the introduction of the cellular concept. In the cellular system design, a given geographical region is split into contiguous regions called "cells," without any gaps in coverage. The system is designed so that cells that use the same frequency band are far enough from each other to cause little interference to each other. The number of different frequency bands is called the reuse factor of the system. The reuse factor is a measure of spectral efficiency in the system, with a larger reuse factor corresponding to a smaller efficiency. A key innovation in the cellular concept is the introduction of handoff between neighboring cells operating in different frequency bands, which allows a mobile user to maintain a continuous connection while moving through the geographical region. Interference management within each of the cells is achieved by orthogonalizing the users in the time–frequency plane (Venugopal, 2018). Figure 1 shows the anatomy of a cellular network.

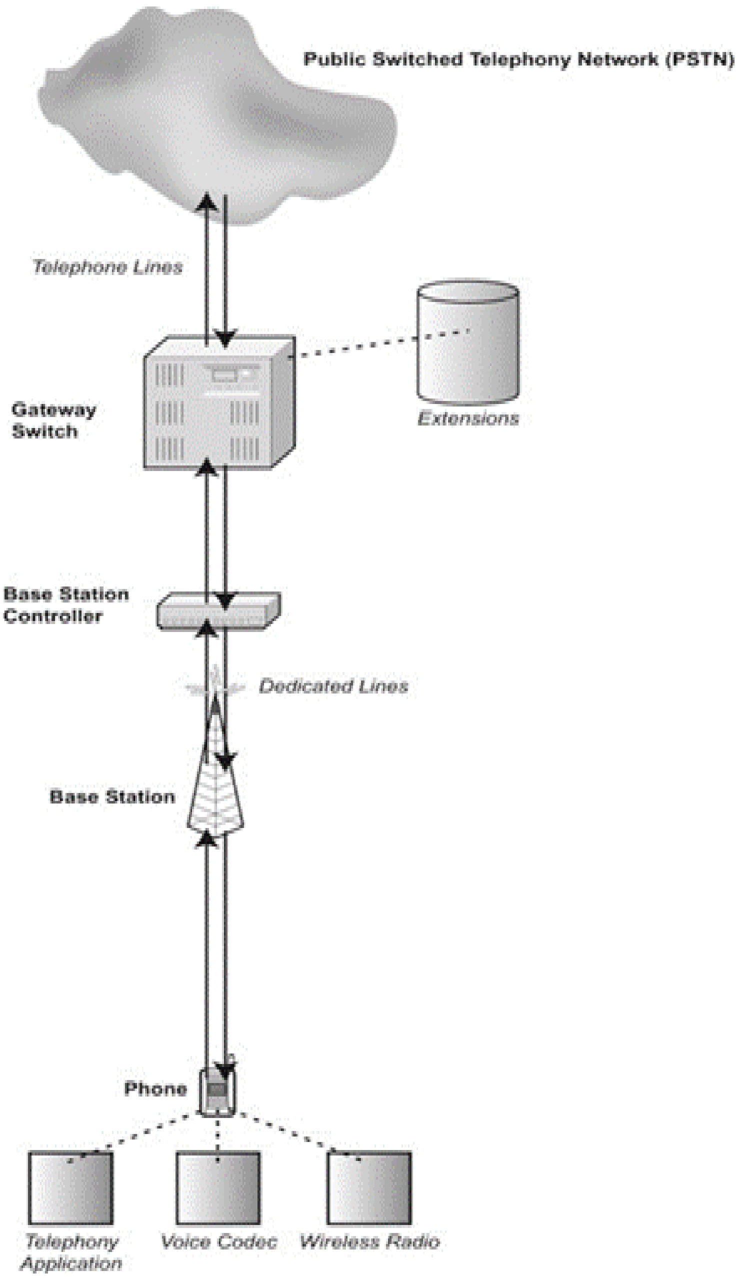

Figure 1. Anatomy of a Cellular Network

A cellular network or mobile network is a communication network where the last link is wireless. The network is distributed over land areas called "cells", each served by at least one fixed-location transceiver, but more normally, three cell sites or base transceiver stations. These base stations provide the cell with the network coverage which can be used for transmission of voice, data, and other types of content. A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed service quality within each cell (Guowang *et al.*, 2016). Cellular networks offer a number of desirable features: More capacity than a single large transmitter, since the same frequency can be used for multiple links as long as they are in different cells. Mobile devices use less power than with a single transmitter or satellite since the cell towers are closer and larger coverage area than a single terrestrial transmitter, since additional cell towers can be added indefinitely and are not limited by the horizon. A simple view of the cellular mobile-radio network consists of the following: a network of radio base stations forming the base station subsystem, the core circuit switched network for handling voice calls and text and a packet switched network for handling mobile data. The public switched telephone network to connect subscribers to the wider telephony network. This network is the foundation of the GSM system network. There are many functions that are performed by this network in order to make sure customers get the desired service including mobility management, registration, call set-up, and handover (Guowang *et al*., 2016).

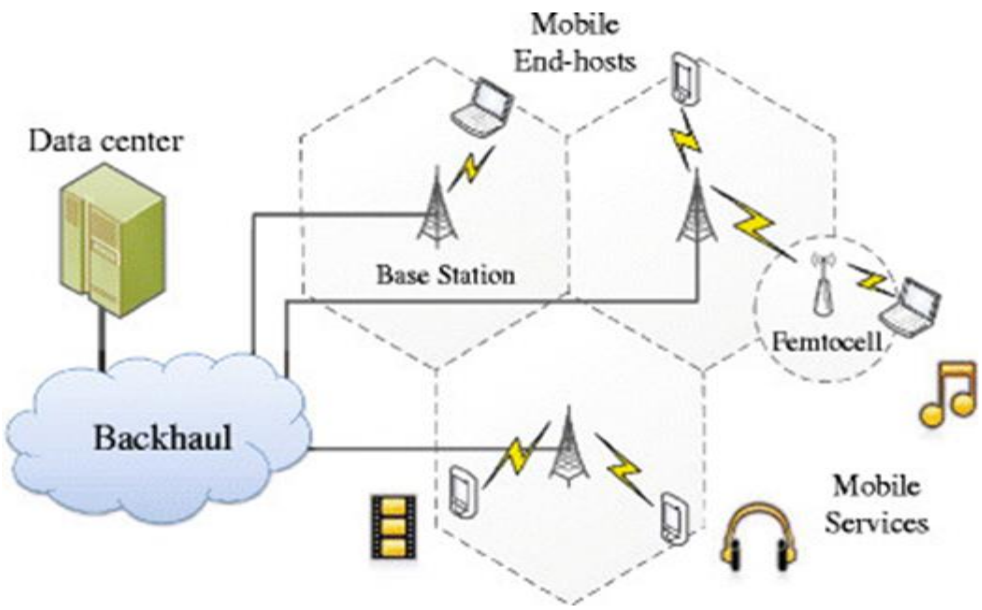

Figure 2. A simplified structure of a mobile cellular network

Types of Interference in Cellular Network

The following types of inference may be associated with wireless networks; Self interference, Multiple Access Interference (MAI), Co-channel Interference (CCI), and Adjacent Channel Interference (ACI).

Self-interference

Self-interference is due to interference induced among signals that are transmitted from a shared transmitter. The amount of interference induced depends on the modulation type. In OFDM, self-interference among sub carriers due to carrier frequency offsets are caused by oscillator mismatches, Doppler Effect and fast fading caused by motion of the transceivers. Transceiver non-idealities such as amplifier non-linearity and IQ imbalance may also be source of self-interference. Interference between the uplink and downlink transmissions in a FD duplex system may be also classified as self-interference, as it occurs among signals send on the same two-way connection. This interference is mitigated by employing duplex filters.

The impact of self-interference may be reduced by selecting the physical layer numerology such that the operating conditions and implementation technology are taken into account. Self- interference cancellation mechanism is shown diagrammatically in Figure 3.

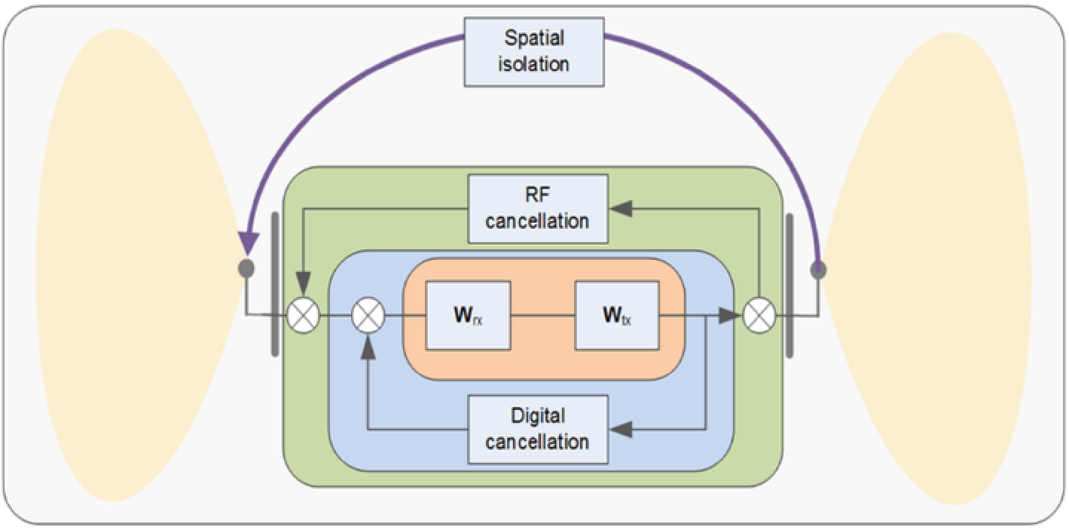

Figure 3. Self-interference Cancellation Mechanisms

Multiple Access Interference (MAI)

Multiple access interference refers to the interference induced among the transmission from multiple radios using the same frequency resource to a single receiver. In theory, the physical layer will allow orthogonal multiple accesses, however, factors such as synchronization errors, RF circuitry non-idealities, and the effect of wireless propagation channel will not allow orthogonality to be maintained in practice. An essential method of maintaining orthogonality in multiple access scenarios is power control. MAI is shown diagrammatically in Figure 4.

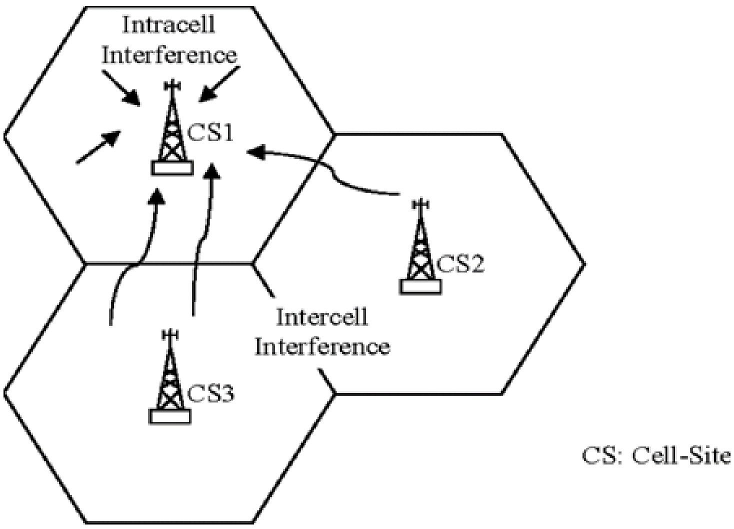

Figure 4. Multiple-Access interference

Co-channel Interference (CCI)

CCI exist between links that reuse the same frequency band (channel). It is also referred to as inter-cell interference in cellular systems. The effect of CCI may be minimized by employing fixed frequency re-use patterns. Common methods for CCI management in cellular networks include: Frequency reuse, MIMO techniques, Interference alignment, and adaptation to interference variation. High frequency re-use factor implies a constant data rate across the service area (reference). This situation leads to similar throughput experience by users at different locations of the cell, and the service rate distribution. Another method of dealing with CCI is by considering co-operation among transmitters. Such techniques have been investigated in the literature under the name of network MIMO (Gesbert *et al*., 2010; Huang *et al*., 2009). In network MIMO, the interference channel is transformed to a broadcast channel by considering the co-operating transmitter as a single transmitter (Janis, 2013). Data traffic may be shared between multiple cooperating transmitters from which it may then be coherently transmitted to the destination receiver as shown in Figure 5.

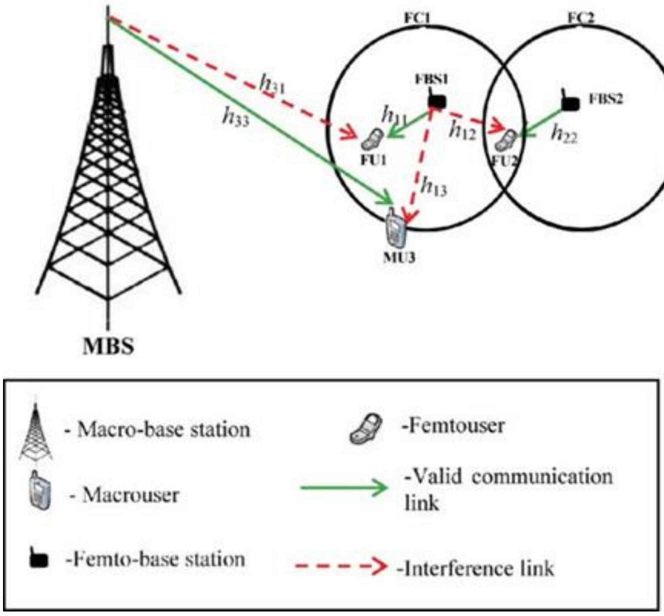

Figure 5. Downlink channel model for co-tier and cross-tier co-channel interferences

Adjacent Channel Interference (ACI)

ACI is the interference induced between links that communicate in the same geographical location using neighboring frequency bands. In its simplest explanation, Interference resulting from signals which are close in frequency to the desired signal is called adjacent channel interference (ACI) as shown in Figure 6. A transmitter occupying a certain frequency band also leaks energy on frequency adjacent to that band. The out-of-band emissions are perceived as interference by other receivers. The effect of the out-of-band emissions may be quantified using the adjacent channel power ratio (ACPR). Signals outside the nominal frequency band generate interference components on the in-band frequencies at the receiver. The adjacent channel sensitivity (ACS) determines the ability of the receiver to cope with an out-of-band interferer. The properties of the RF chain that contribute to ACS characteristics include; the quality of channel selection filters, analogue-to-digital converter bit width, and the linearity of amplifiers and mixers.

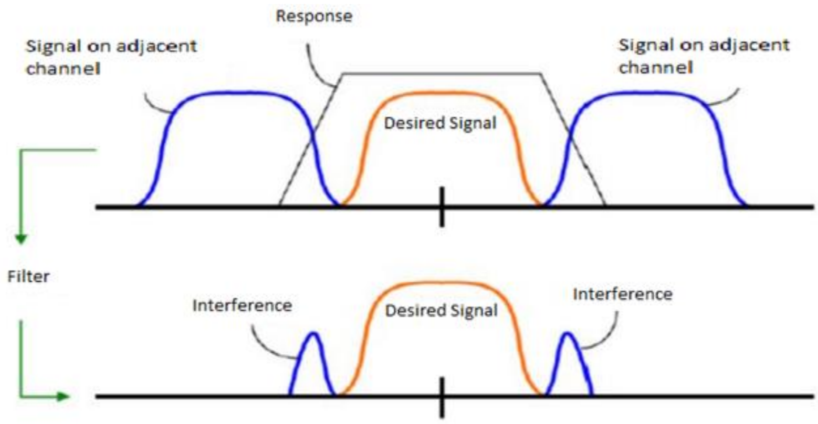

Figure 6. Adjacent Channel Interference

Interference Reduction Techniques

The interference Reduction Techniques in cellular network are x-rayed as follows.

Intermodulation Solutions

The amplitude modulation of signals containing two or more frequencies in a system with non-linearity is referred to as intermodulation. Intermodulation between constituent frequencies will result in additional signals at frequencies that are not just at harmonic frequencies of either, but also at the sum and difference frequencies of the original frequencies and at multiple of those sum and differences. The types of intermodulation of interest in co-located Base Stations (BS) are; forward and reverse intermodulation (RIM). Forward intermodulation (FIM) components are induced in the victim receivers and are of major concern when they fall directly on the required signal. A knowledge-based filtering method was used in German *et al*. (2010) to eliminate the FIM components. This method relies on the knowledge of co-located transceiver specifications and antenna configurations which makes it unsuitable for dynamic environments. Demirkiran *et al*. (2010) described another approach that located the jamming signal by scanning the spectrum with Fast Fourier Transform (FFT) and then removed it with a tunable notch filter. The disadvantage of this approach is that it adds extra filter complexity issues and it does not help in mitigating the RIM distortions at the transmitter end.

Frequency Planning Methods

Frequency (channel) allocation in cellular networks is an important subject amongst researchers, optimization engineers and mathematicians. The population of Mobile Users (MU) increases daily while available spectrum remains fixed. Hence, the frequency allocation problem is modeled as a multi-objective, multi-constraint optimization problem where given a number of Base Station (BS) and available channels it is required to find an optimal frequency plan that satisfy the channel demands of MU in a geographical area and the interference constraints.

Genetic Algorithms

Evolutionary computation (EC) is a computational approach that models biological evolutionary principles to solve mathematical optimization problems. The field of evolutionary computation is sub-divided into; genetic algorithms, genetic programming, evolutionary strategies and evolutionary computation. EC draws mainly from the concept of biological genetics hence terminologies such as mutation, crossover, parent, chromosomes, genes, genome, selection etc. are used quantitatively to define processes involved in applying

EC to optimization problems. Numerous research papers have been developed to apply Genetic Algorithms (GA) to the channel assignment problem (GA).

Simulated Annealing

Simulated annealing is a local search technique that models the physical annealing process where a crystal is cooled from liquid state to solid state. The terminologies that define the processes in simulated annealing are; initial solution, temperature, cooling strategy and fitness function. The initial solution is a randomly generated solution that defines the start point of the search algorithm. The fitness function is a function that measures the effectiveness of a particular solution to the problem. The acceptance probability of a solution in the search space is controlled by the temperature while the cooling strategy defines how the algorithm explores the search space.

Duque-Anton *et al.* (1993) applied simulated annealing to the minimum interference frequency assignment problem (MI-FAP). A dummy frequency was introduced to serve (partially) an unsatisfied demand. The dummy frequency substitution implies increasing or decreasing the violation of traffic demand. The performance of the algorithm is increased; a new frequency is allocated dynamically as the most frequency assigned to close non-interfering matrices

Ant Colony and Multi-agent Optimization

The term “swarm intelligence” was first used by Beni and Wang (1993) to refer to the collective behavior of decentralized, self-organizing systems, artificial or natural interacting locally with their environment thereby causing a coherent functional global pattern to emerge. Ant-colony optimization (ACO) algorithms are mathematical algorithms that mimic the behavior of ants when searching for food. Mathematicians and optimization enthusiasts model the intelligent behavior of ants when searching for an optimal path between food source and their nest while relying on feedback from their environment through the deposition of pheromones along possible paths to a potential food source.

Artificial Neural Networks

The term “Artificial Neural Networks” is used to refer to artificial systems that draw inspiration from the method of information processing by the biological neural networks. Analogues such as neurons, axons, dendrites, synapses etc. are used to model a computational information processing system. The computational mechanism used in ANN is known as learning. Two types of learning are prominent in ANN; supervised and unsupervised learning. In supervised learning, the neural network performs computation by mapping information from previous data (presented to the network) about the particular system under consideration. Unsupervised learning projects data about a system onto an N-dimensional space using neurons to represent the different data elements. For spectrum allocation, the unsupervised learning approach is usually applied. A neuron represents a cell and it contains information about the cell demand and the cell frequencies. The neurons in the network are interconnected by a mathematical (energy) function such that the interference constraints and demand constraints are embedded. The learning process here runs iteratively until a minimum value of the energy function is achieved.

Conclusions

The above review shows that numerous techniques are available for addressing the problems of interference in cellular networks. While many of these techniques seem to work more effectively in some areas of operations, others show strong applications in other areas. However, challenges abound in current situation as some of these techniques have not been given field applications. Among several techniques available to address interference networks, EAs has been given wider applications and the results show good performance of this technique. Meanwhile, genetic algorithm is also efficient where applied, but to take interference in current and future mobile communication network deployment under bearable check, synchronization of reduction techniques where traffic driven factors such as war and population drift are considered may be the best.

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