Applications of Soft Computing in Mobile and Wireless Communications

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ABSTRACT
Soft computing is a synergistic combination of artificial intelligence methodologies to model and solve real world problems that are either impossible or too difficult to model mathematically. Furthermore, the use of conventional modeling techniques demands rigor, precision and certainty, which carry computational cost. On the other hand, soft computing utilizes computation, reasoning and inference to reduce computational cost by exploiting tolerance for imprecision, uncertainty, partial truth and approximation. In addition to computational cost savings, soft computing is an excellent platform for autonomic computing, owing to its roots in artificial intelligence. Wireless communication networks are associated with much uncertainty and imprecision due to a number of stochastic processes such as escalating number of access points, constantly changing propagation channels, sudden variations in network load and random mobility of users. This reality has fuelled numerous applications of soft computing techniques in mobile and wireless communications. This paper reviews various applications of the core soft computing methodologies in mobile and wireless communications.

General Terms
ANN, LTE, Mobile communication, Soft computing, Wireless communication.

Keywords
Soft computing, wireless networks, MBWA, WiMAX

1. INTRODUCTION
The concept of soft computing (SC) is an important thesis in the area of intelligent and knowledge-based systems introduced by Zadeh [1]. Soft computing is patterned after human reasoning which is mostly qualitative, approximated and soft; in order to handle fuzzy, incomplete and imprecise information. It is an effective complement of conventional artificial intelligence in the domain of computational intelligence. The European Centre for Soft Computing defines it as "A set of computational techniques to solve problems by imitating nature's approaches." The core disciplines of soft computing are genetic algorithms, fuzzy logic, probability theory and Artificial Neural Networks (ANNs). These disciplines are used cooperatively or as hybrids for reaping the advantages of two or more of these techniques. Soft computing has been applied to a number of industrial applications such as Transportation [2, 3, and 4], Manufacturing Automation [5], Intelligent Agent Systems (Robots) [6], Electric Power systems [7] and Consumer Appliances [8]. Other industrial applications of soft computing are outlined in [9].

The explosion in demand for wireless services and broadband internet access has fuelled a number of parallel developments in wireless communications. The emergence of 3G (e.g. UMTS and CDMA 2000) and 4G (IMT-Advanced) cellular networks, Wireless LANs (Local Area Networks), WiMAX (IEEE 802.16) and Mobile Broadband Wireless Access (IEEE 802.20) are examples of development in wireless communications. The rapid evolution of wireless networks has also generated intensive research in to realizing reliable and efficient communications over the wireless channel. To this end several conventional and soft computing techniques have proposed for different aspects of wireless communications. In [10], the use of soft computing in the mobile wireless communications was classified into three broad categories, namely, optimization, prediction and uncertainty management. The scope of wireless communications extends to four very crucial areas, namely: broadcasting, Radio link systems, Wireless Local Area Networks and cellular mobile communication. These areas of wireless communication form the basis of this review.

2. SOFT COMPUTING TECHNIQUES
Soft computing and its associated methodologies are new, thus there is a tendency for expansion beyond its original scope and definition. In retrospect, the idea of extended soft computing was proposed in [11] by incorporating immune Network Theory and Chaos Computing. In the same vein, Fuzzy logic, which is the foundation of soft computing has been expanded [12]. Given that soft computing is still growing and developing, there is no distinctive definition of what constitutes soft computing. Thus, this article sticks to the core techniques proposed by Lotfi Zadeh and their hybridization.

Artificial Neural Networks are a non-algorithmic (do not require critical decision flow in their algorithms) approach to information processing inspired by the biological nervous systems. ANNs are based on connectionist architectures that model the brain in a continuous-time nonlinear dynamic system so as to mimic brain mechanisms of intelligent behavior [13]. Processing of Information occurs at many simple processing elements called nodes (also known as cells, units or neurons). Each connection link between nodes is associated with a weight, which controls the behavior of the trained ANN. The main merits of ANN are distributed memory, parallelism, generalization capability, learning and redundancy. However, ANNs have some drawbacks that need to be complemented by other techniques. Neural networks are "black box" in nature; they do not provide the meaning of weight changes that gives a particular input-output

relationship. Additionally, it is challenging to determine the proper size and structure of an ANN to solve a particular problem. Wireless applications are inherently nonlinear in nature. The non-linearity associated with wireless makes ANN more robust and effective than conventional linear procedures in wireless networks. In this vein, wireless networks are associated with much approximation. ANNs are universal approximators capable of approximating any nonlinear function. Another edge of using ANN in wireless communications is the great generalization power of Artificial ANNs. This is especially important because wireless network phenomena are non-repeatable. Thus a single implementation of ANN can be used to model several scenarios. ANNs also help offset the computational cost associated with complex mathematical and electromagnetic analysis.

Fuzzy logic is a methodology for representing uncertain and imprecise knowledge, first developed by Zadeh [14]. Fuzzy logic models the human mind using what is known as fuzzy logic controller for providing an approximate but effective mechanism of describing systems that are difficult, ill-defined or too complex for mathematical (traditional) analysis. Fuzzy logic offers simplicity, flexibility and cost effectiveness. However, there is no standard method to develop the knowledge base for making inferences from fuzzy logic system. Moreover, in order to minimize the output error measure and maximize performance index, an effective method for fine-tuning the membership function is needed [15]. When dealing with wireless networks, it is impractical to obtain a comprehensive knowledge of all factors. This emphasizes the need for a method or means of tracking uncertainty and ambiguity. Fuzzy logic uses human expert knowledge in a rule based framework for solving a variety of problems in wireless and mobile networks.

Genetic Algorithm is an optimization and search methodology grounded on the foundations of genetics and natural selection (evolutionary behavior of living creatures) [16]. It involves the creation of a population "strings" based on parent genes. The strings (offspring) are evaluated based on their utility functions. The best string is selected to be the new parent of the next generation (genetic manipulation). Genetic algorithm can optimize both continuous and discrete variables and it doesn't require derivative information. It works well with a large number of variables and deals with numerical or experimental data as well as with data generated from analytical functions. Optimization is gaining more importance in wireless communications as result of increasing complexity of new technologies, parallel operation of different wireless networks and the pressing need for efficient use of available of spectral and network resources. Genetic algorithm presents itself as a very effective tool for addressing the multi-faceted optimization needs of wireless networks.

These fields of soft computing can be fused together to augment for the demerits of one technique by the merits of another [17]. For example, genetic algorithm can be used to optimize neural network parameters such as input columns, the number of hidden nodes, the number of memory taps and the learning rate. In the same vein, neural network can be used for tune the membership functions of fuzzy inference system and improve its learning and generalization capability. This translates into improved capacity to create more innovative applications.

3. SC IN WIRELESS WIDE AREA NETWORK

Wireless Wide Area Networks (WWANs) use mobile telecommunication cellular networks such Mobitex, GSM, CDMA2000, UMTS, WiMAX and LTE for data transfer. Table 1 (Appendix A) gives a comprehensive summary of some of the domains of application in WWANs.

Resource allocation is aimed at utilizing the limited system resources optimally in order to accommodate the maximum number of subscribers possible with the acceptable grade and quality of service. Some of the pressing resource allocation issues include rate adaptation, multiple access schemes, relay assignment in cooperative networks etc. Resources are normally allocated over time-varying wireless channels, which make soft computing techniques readily applicable. The methodology to be adopted largely depends on how the resource allocation problem is formulated.

The size and complexity of WWANs, makes prediction of various components indispensable. Predictions are used for channel measurements, propagation prediction, node placement and positioning, network planning, tracking user mobility etc. The principal soft computing technique for prediction is neural network, as it is capable of tracking non-linear relationship from historic data.

The objectives of power control are wide and range maintaining constant signal to interference noise ratio so as to achieve constant bit rate to conservation of battery life in mobile stations. Power control is also essential to combat the 'near-far effect', reduce adjacent cell interference, exploit favorable channel conditions and enhance network capacity. It is conceptually a resource allocation issue which embraces a wide objective. Several methods and algorithms for power control have been proposed. Some these methods are: Eigen signal to interference ratio balancing methods, iterative methods based on Yates framework, distributed algorithms, joint power control with stepwise removal and outage based power control. The use of soft computing has been extended to power control to reduce computational complexities and iterative procedures.

Handoffs involve change of radio resource for a connected user initiated by deterioration of quality of signal in the serving base station/channel or when a radio cell boundary is crossed. An optimized handover requires multiple input parameters which can be adequately handled using soft computing. Fuzzy based methodologies offer a good platform for handoffs.

Load balancing is a self-organizing network operation that is achieved using handoffs. It can be based on the same platform

with handoffs while using the desired load and key performance indicators for an optimized solution. A summary of applications of soft computing in wireless wide area networks is given in Table 1 (see Appendix A).

4. SC IN RADIO LINK SYSTEMS

Radio links provide transmission access through the use of stationary or semi-stationary radio connection based on radio relay stations or satellites. Four basic classification of radio links are: satellite links, Visual links, scattering links and ionosphere links. Due to possibility of mobility, weather effects, impacts of distance etc. radio links are associated with much uncertainty as well as critical planning and scheduling requirements. Table 2 (Appendix B) gives some applications of soft computing to address some of these non-linear problems.

The process of planning radio links normally involves extensive feasibility and budgetary analysis, station coordinates path topology, reflection analysis, link analysis etc. This tedious task of repeating these processes to achieve an optimal solution can be eliminated by using soft computing. Neural network can map out the complex relationship among the various parameters and genetic algorithm can be leveraged to optimize the available resources.

Satellites are subject to perturbing forces such as solar radiations, rotational deformation, air drag, ocean tide etc. These effects are stochastic and unpredictable, which limits the capability of the mathematical modeling. However, using soft computing techniques, much of the task of control can be implemented in the space station, which translates into reduced operational costs. In terrestrial radio links, control of antenna beam-forming and other related operations can leverage on SC techniques.

Scheduling of radio resources is an application with extensive scope. It is essential for minimizing interference, maximizing network stability, minimizing energy consumption etc. The SC methodology to be adopted invariably depends on the objective of the scheduling task. Neural networks are universal classifiers. Thus they provide a SC basis for use applications such a satellite imaging and other multimedia processing tasks such as speech recognition. A table summarizing the different applications of soft computing in Radio Link Systems is presented in Appendix B.

5. SC IN WIRELESS LAN

Wireless Local Area Networks (WLANs) are used to connect users to wired structure of a corporate network. WLANs are based on the IEEE 802.11 standard, which provides high data rates and robust radio frequency connectivity to the wired infrastructure. Because WLANs are directly associated with the core network of the corporation, security is a critical factor in the management of the network. The diverse disparity in wireless and wired technologies gives rise to the need of adequate control, scheduling of resource and network planning. Soft computing methodologies proposed to solve a

number of these challenges. Table 3 (Appendix C) outlines the applications of these techniques to key areas of WLANs.

One of the basic needs of WLANs is effective security against intruders. This is especially pressing because some WLAN standards have loosely packaged security specifications. ANN provides a platform that can be enhanced with other SC techniques to detect and prevent network intrusions and other related attacks.

6. SC in Wireless PAN and HetNets

Wireless Personal Area Networks (WPANs) are based on the IEEE 802.15 standard. WPANs are carried over wireless technologies such as Body Area Networks, Bluetooth, Infrared Data Association (IrDA), Wireless Fidelity (Wi-Fi), and ZigBee. The most important resource for WPAN is power. Various soft computing techniques have been proposed for efficient power management in WPAN. Table 4a (Appendix D) details this and other uses of soft computing in WPANs. Some innovative uses of soft computing for heterogeneous wireless communication networks are also outlined in Table 4b of the same appendix.

Some of the most vital applications of SC in WPAN are mobility tracking, power control and optimization. Mobility tracking is vital, since most nodes and users in the network are closely related. WPAN applications are meant to be low power devices so as to preserve battery life. Additional power savings can be achieved by reducing computational intensity and rigor through the use of fuzzy based SC techniques.

7. Conclusion

We have presented in this paper an extensive review that captures diverse uses and application of soft computing techniques in wireless communications. The advantages of using soft computing include robustness, cost effectiveness and simplicity. Though the application areas can be broadly classified into optimization, uncertainty management and prediction, combining soft computing techniques have been shown to effectively solve problems that cut across these boundaries. Genetic algorithm (and other evolutionary computing techniques) have been shown to be very useful in optimization problems such as network design, antenna design and resource allocation. ANNs offer powerful prediction capability due to its great generalization power and learning capability. Fuzzy logic, which is the backbone of soft computing, is suitable for tracking imprecision and uncertainty. This is very useful for innovative control, load balancing and handoff decisions. Wireless and mobile communications applications are subject to the uncertainty, ambiguity, nonlinearity and complex nature of their respective networks. This makes SC a veritably the alternative of choice for cost effective solutions. Combing the various SC methodologies together have been shown to offer more innovative, robust and powerful solutions that were hitherto deemed impossible

8. REFERENCES

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Appendix A
Table 1: Summary of applications of soft computing in WWAN

Application	Description	SC Method	Source
Resource Allocation	Bandwidth allocation schemes for cellular mobile networks aimed at maximizing bandwidth utilization and minimizing bandwidth allocation for individual users.	ANN	[18]
	An optimal solution for frequency assignment with minimum number of channels and cost function in heterogeneous cellular network was proposed	ANN	[19]
	The use of hybrid methodologies to develop an algorithm for optimized radio channel allocation and minimized call dropping was presented.	GA, FL	[20]
Prediction	A 3G radio network planning modified using a soft-computing platform. The predictions of the radio-planning tool were improved.	FL	[21]
	Uses a soft computing Inference system for video quality prediction over UMTS (universal mobile telecommunication system). A combination of physical and application layer parameters were used for the model.	ANN, FL	[22]
	A technique for predicting the location of a mobile user in a cellular network was proposed. Different neural network architectures were used and contrasted.	ANN	[23]
Power Control	Power control in DS-WCDMA was achieved using a soft computing algorithm. The algorithm has the merit of reducing mobile terminal power consumption as well as increasing the cellular radio network capacity.	EC	[24]
	A soft-computing system was designed for power control in a wireless cellular radio network. The core aim of this approach is to maximize the lowest carrier to interference ratio (CIR) among the users.	ANN, FL	[25]
Optimization	The complex task of determining the number of cells, the optimal cell sites and parameter, coupled with the need to minimize both spectral and financial cost in order to meet system and budgetary requirements were addressed using soft computing.	GA, FL	[26]
	The use of Relay in beyond 3G cellular networks is a promising architecture. Thus it is necessary to optimize the parameters of the system, which include reuse pattern, path selection and placement of relay stations.	GA	[27]
Handoff/Call Admission Control	The criteria for call admission control and handover are inherently imprecise. Since soft-computing exploits tolerance for imprecision, it is employed in this scenario for realizing an improved real time performance.	FL	[28]
Load Balancing	Mobility load balancing is one of the self-organizing operations for wireless networks. A robust platform for dynamic load balancing in 3GPP LTE was achieved using load indicators and key performance parameters.	ANN, FL	[29], [30]

ANN – Artificial Neural Network; FL – Fuzzy Logic; GA – Genetic Algorithm; EC – Evolutionary Computation.

Appendix B
Table 2: Summary of applications of soft computing in Radio Link Systems

Application	Description	SC Method	Source
Radio Planning	Topographic and morphological data were used for prediction of mobile radio field strength. The system can be incorporated into an adaptive radio-planning tool.	ANN	[31]
Control	A soft-computing control method to improve the accuracy and robustness of three-axis stabilized satellite. This approach effectively deals with the external disturbances and uncertainties associated with satellite space system.	ANN, FL	[32]
Scheduling	The task of link and/or broadcast scheduling is a nondeterministic polynomial time (NP) problem. The objective of the algorithm is to obtain the broadcasting schedule of satellite with the highest number of broadcasting time slots.	ANN	[33]
Satellite Imaging	Images from satellites photos are used to classify objects such as trees, roads and rivers. Soft computing is used synergistically to categorize objects from air photos and satellite images based on their features with the least acceptable errors.	ANN, FL, EA	[34]
Prediction	Prediction in satellite and other microwave links is used to determine a number of factors such as the impact of scatterers like rainfall on the performance of the link. This problem can be addressed using a methodology based on an inference system.	ANN, FL	[35]

Appendix C
Table 3: Summary of applications of soft computing in WLANs

Application	Description	SC Method	Source
Security	Denial of service (DoS) attack is common in local area networks. It is achieved by an attacker flooding an application with large amounts of legitimate request. A soft computing system is developed to minimize the detection delay for de-authentication of DoS attacks in WLANs.	ANN, FL	[36]
Planning	Planning a WLAN can be complicated and time demanding. A combination of prediction and optimization methodologies can used strike a solution that good quality solution within a reasonable frame of time.	ANN, GA	[37]
Prediction	The stochastic and unpredictable nature of traffic in WLAN gives rise to difficulty in network management. A network model was developed to predict the Quality of service of WLAN	ANN	[38]
Control	One of the bottlenecks in WLAN is that of traffic flow from wired network to wireless network due to disparity in channel capacity. One of the veritable solution to this problem is the use of congestion control mechanisms in access points.	PSO, FL	[39]
Optimization	With increase in demand for diverse services, access point allocation needs to adequate cater for challenges such as quality of service, bandwidth allocation and load balancing. An evolutionary algorithm can be used access points placement based on desired parameters.	GA	[40]

Appendix D
Table 4a: Summary of applications of soft computing in WPAN

Application	Description	SC Method	Source
Tracking	Personnel location in a wireless personal area networks (WPANs) is very important. Thus, there is a need for a model to manage this uncertainty problem.	FL	[41]
Power Control	Transmissions of video over wireless links are associated with a compromise between energy constraints, display and decode deadlines and channel conditions. Significant power savings is achieved by exploiting the tolerance for imprecision.	FL	[42]
	Wireless Body networks used as wearable devices or can be embedded in the human body. The most important resource for these devices is power, which can be degraded by interference by interference from similar network. A power control methodology was used to achieve substantial reduction in power consumption.	FL, GA	[43]
Optimization	Optimizing the ground plane shape of antennas is very vital for broadband applications. A cost effective procedure was used to increase antenna bandwidth by up to 2.5 times.	GA	[44]

Table 4b: Summary of applications of soft computing in Heterogeneous wireless communication networks

Application	Description	SC Method	Source
Handoff	One of the basic requirements of heterogeneous wireless network is seamless mobility across all interfaces. A non-conventional approach of using multiple parameters based algorithm to realize a gain in throughput and a reduction in ping pong effect which consequently improves the quality of service of the heterogeneous network.	ANN, FL	[45]
Resource Allocation	Heterogeneous network operations is inherently associated with resource allocation due to disparity in a number of factors such access technology, capacity etc. An algorithm based on connectionist system can be used to achieve fast and suboptimal solutions for joint dynamic resource allocation.	ANN	[46]
	A methodology capable admission control, traffic classification, resource estimation for reservation and RAT (radio access technology) selection was used for load balancing, handoff and admission control.	FL	[47]
Network Optimization	Access points node placement is a nondeterministic polynomial time problem that is more intractable in heterogeneous wireless networks. This problem was solved using a multi-objective adjustable length algorithm.	GA	[48]