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Particle swarm optimization based network selection in heterogeneous wireless environment

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ABSTRACT

Deployment of heterogeneous wireless networks is spreading throughout the world as users want to be connected anytime, anywhere, and anyhow. Meanwhile, users are increasingly interested in multimedia applications such as audio, video streaming and Voice over IP (VoIP), which require strict Quality of Service (QoS) support. Provisioning of Always Best Connected (ABC) network with such constraints is a challenging task. Considering the availability of various access technologies, it is difficult for a network operator to find reliable criteria to select the best network that ensures user satisfaction while reducing multiple network selection. Designing an efficient Network selection algorithm, in this type of environment, is an important research problem. In this paper, we propose a novel network selection algorithm utilizing signal strength, available bit rate, signal to noise ratio, achievable throughput, bit error rate and outage probability metrics as criteria for network selection. The selection metrics are combined with PSO for relative dynamic weight optimization. The proposed algorithm is implemented in a typical heterogeneous environment of EDGE (2.5G) and UMTS (3G). Switching rate of the user between available networks has been used as the performance metric. Moreover, a utility function is used to maintain desired QoS during transition between networks, which is measured in terms of the throughput. It is shown here that PSO based approach yields optimal network selection in heterogeneous wireless environment.

1. Introduction

The next-generation wireless networks consist of various mobile and wireless technologies. Due to complementary characteristics of different wireless networks, it is necessary to combine them to provide ubiquitous wireless access for users. The integration of heterogeneous wireless networks (HWNs) requires the design of intelligent network selection algorithm to ensure seamless communication, and provide high QoS for different multimedia applications [1].

A heterogeneous wireless network is composed of two or more wireless access technologies. Each access technology involved in HWN has its own characteristics in terms of coverage, QoS support, and operational costs. Users with multi-interface terminals are able to initiate connectivity through the access technology that best suits their attributes and the requirements of their applications. The main advantage of HWN lies in its ability that users can maintain their sessions when moving between different networks. This enables users to continuously select the most appropriate network during their communication. For network operators, HWN paves the way to higher profitability through more capable networks where complementary advantages of individual technologies are combined [2]. For example, EDGE network supports upto 384 Kbps. Over a wide geographical area while UMTS cellular networks can provide upto 2 Mbps in a smaller coverage.

In this paper, we focus on the selection of always best connected network in heterogeneous environment while maintaining QoS for multimedia services. Heterogeneous environment may consist of number of overlay wireless technologies. Proposed network selection model is represented in Fig. 1.

Initially monitor the networks present in heterogeneous environment of multimode mobile station (MS). Received signal strength (RSS) is used to sense the presence of wireless networks. If the MS detects a single wireless network (WN_1) then it is automatically connected to it. But when the MS senses more than one wireless network (such as WN_1,. . . . . . .,WN_n) at the same time then the problem of network selection comes into the picture for best QoS. In the proposed model, first observe the physical layer metrics (such as averaged RSS, outage probability, available bit rate (ABR), signal to noise ratio (SNR), bit error rate (BER) and achievable throughput) of available networks in heterogeneous environment

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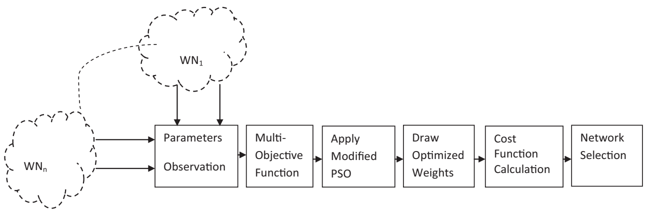

Fig. 1. Proposed network selection model in wireless heterogeneous environment.

to perform a network selection. Then calculate the multi-objective function NSDF (Network Selection Decision Function) based on observed physical layer metrics. The relative weights of each network selection metric are dynamic to several available wireless networks. Dynamic weights relative to selection metrics are optimized by using modified PSO (particle swarm optimization). Cost function is calculated based on observed physical layer metrics and relative optimized weights. The network having greater cost function value is selected as the Optimum network (ON) in the given heterogeneous environment while maintaining QoS for multimedia services such as audio streaming, geographical mapping etc.

The rest of the paper is organized as follows: Section 2 explains the work related to network selection algorithm on heterogeneous radio access technology, Section 3 describes the system model and Section 4 represents implementation of the proposed network selection algorithm. Performance evaluation of proposed algorithm is discussed in Section 5. Finally, conclusions are drawn in Section 4.

2. Related work

Many network selection algorithms have been proposed in literature. Artemis and Koutsorodi et al. focused on terminal-initiated and terminal-controlled access network selection in heterogeneous networks. Network status, resource availability, user preferences and service requirements determined the optimal local interface and attachment point [3]. Giupponi et al. used the fuzzy neural mechanism for the selection of best RAT among UMTS, GERAN and WLAN [4]. Khan et al. considered a user-centric network selection approach where negotiation between users and network operators was carried out using multi attribute auctioning mechanism. To reduce frequency of handovers, fuzzy logic approach was used in auction mechanism [5]. The authors in [6] utilized past knowledge of the service performance of available wireless networks to make a decision for network selection on given time intervals. They used PSO, fuzzy logic controllers, as well as genetic algorithm for optimization of decision making based on multi-criteria inputs. Porjazoski and Popovski presented an algorithm for radio access technology selection in heterogeneous wireless networks based on service type, user mobility and network load [7]. Its performance was evaluated using two-dimensional markov chain. Yang and Tseng proposed a scheme using a self-developed attribute rating method WRMA (Weighted Rating of Multiple Attributes) and a MADM (Multiple Attribute Decision Making) theory–TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) for network selection in heterogeneous wireless networks [8].

Kunarak and Suleesathira presented policies in the merit function to select an optimal target network [9]. Dwell time calculation has been proposed depending on the user speed and moving pattern as a selection metric. It outperformed in reducing the number of vertical handoffs and grade of service while increasing the average utilization per call of WLAN/WiMAX networks. A fuzzy logic technique combined with GRA classification method for efficient network selection was proposed in [10]. Alkhawlani and Abdulqader developed Radio Network Selection (RNS) solution by using combined effect of parallel fuzzy logic control and multi-criteria decision making (MCDM) system to achieve scalable, flexible and adaptable selection solution [11]. Yee et al. introduced load distribution model to facilitate better network selection using PSO. The network resource was optimized with an objective to distribute the system load according to the various conditions of the heterogeneous networks and to achieve minimum system cost [12]. Optimizing the selection process is an important issue of research, which leads to reduction of network signaling and mobile device power loss and on the other hand improves network Quality of Service (QoS) and Grade of Service (GoS).

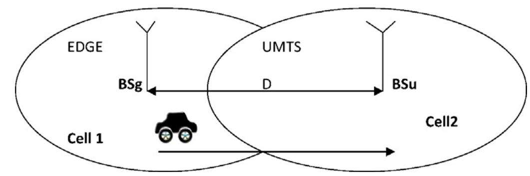

Fig. 2. Heterogeneous wireless network model.

The main focus of this paper is to achieve better QoS while selecting ABC network, using a novel network selection algorithm based on NSDF (Network Selection Decision Function). NSDF utilizes dynamic optimized weights to select ABC in heterogeneous environment of cellular networks. Dynamic weights of the parameters used in the cost function for network selection are optimized using modified PSO algorithm.

3. System model

In this section, we introduce network model of proposed network selection algorithm. Heterogeneous environment may consist of number of different wireless networks. For simplicity, without loss of generality, we consider a heterogeneous wireless network consisting of EDGE and UMTS cellular networks as shown in Fig. 2. It is assumed that a user is traveling at a constant speed in a straight line and MS may move from the cell which is served by base station 'BS_g (EDGE)', toward another with 'BS_u (UMTS)' at constant speed along a straight line and vice versa. Where, 'D' is the distance between the two base stations. MS samples the pilot signal strength at regular distance intervals as

$$d = kd_s \tag{1}$$

where d_s is the sampling distance ($d_s = 1$ m) and k, an integer with $k\ \varepsilon\ [0, D/d_s]$ [13]. Both the base stations are assumed to be located and operating from the center of the respective cells with equal transmitting power.

Selection metrics of cellular networks in heterogeneous environment are discussed as follows. RSS at MS affected by three components, i.e., path loss attenuation with respect to distance, shadow fading and fast fading. Path loss is the deterministic component of received signal strength, which can be evaluated by propagation path loss models [14,15]. The pilot signal strength received by MS from BS_g and BS_u respectively can be expressed in dBm as:

$$S_i(k) = K_1 - 10\gamma_g \log\ 10(kd_s) + \xi_g \tag{2}$$

$$S_i(k) = K_1 - 10\gamma_u \log\ 10(D - kd_s) + \xi_u \tag{3}$$

where, K_1 is a path loss parameter and γ_g and γ_u are the path loss exponents for EDGE and UMTS cell environments, respectively. $i = 1$ & 2 for EDGE and UMTS cell respectively. Shadowing is caused due to the obstruction of the line of sight path between transmitter and receiver by buildings, hills, trees and foliage, where the transmitted signal power is blocked and hence severely attenuated by the obstruction. The amount of shadow fading is dependent on the relative positions of the transmitter and receiver with respect to the large obstacles in the propagation environment. ξ_g and ξ_u denote the shadow fading components in above Eqs. (2) and (3). The autocorrelation function of shadow fades is given in Eqs. (4) and (5)

$$E\{\xi(k)\xi(k+m)\} = \sigma_s^2 \alpha|m| \tag{4}$$

$$\alpha = \exp\ (-\nu T_m/d_0) \tag{5}$$

where σ_s is the standard deviation of shadow fading and m is an integer. The same value of standard deviation σ_s for both cells is assumed. d_0 is the correlation distance, T_m is the sampling time, and ν is velocity of the MS; hence $d_s = \nu T_m$ [16]. To reduce the multiple network selection at the same time instance and to alleviate the impact of shadow fading, the measured signal strength samples are averaged over a rectangular window defined in Eq. (6) before these could be used to select the network [17].

$$S_{ai}(k) = \frac{1}{N_W}\sum_{n=0}^{N-1} S_i(k-n)W_n \quad i = 1, 2 \tag{6}$$

where $S_{ai}(k)$ is the kth sample received from BS_i after averaging. W_n is the weight assigned to the sample taken at the end of $(k-n)$th interval, and

$$N_W = \sum_{n=0}^{N-1} W_n \tag{7}$$

For a rectangular window, equal weight is given to all the previous samples in the averaging window N_w defined in Eq. (7) therefore, $W_n = 1$ for all n. Fast fading is due to multipath reflection of a transmitted wave by objects such as houses, buildings other manmade structures or natural objects such as forests surrounding the MS. It is neglected for network selection initiation trigger due to its short correlation distance relative to that of shadow fading [18]. Standard deviation of averaged shadowing samples can be obtained as:

$$\sigma^2 = \frac{(\sigma_\downarrow S\uparrow 2)}{N}[1 + 2 \times \sum\nolimits_\downarrow (n=1)^\uparrow (N-1)] \quad (1 - \frac{n}{N})\rho\uparrow n \tag{8}$$

where, σ_s and σ are the respective standard deviations of shadow fading before, and after taking average of signal strength measurements over N samples. The symbol 'ρ' denotes auto-correlation coefficient of the shadow fading.

Outage probability is a selection metric derived from averaged RSS. It is defined in Eq. (9) as the probability that the averaged received signal strength is less than a certain threshold.

$$P_i = P[\Gamma < \Gamma_t] \quad i = 1, 2 \tag{9}$$

Γ is averaged received signal strength of cellular network present in heterogeneous environment and Γ_t is the threshold received signal strength. The threshold depends on the impact of cellular network types in heterogeneous environment [19].

Another metric for network selection algorithm is Available Bit Rate (ABR). It is derived from Shannon Channel Capacity formula defined in Eq. (10). It depends on the channel bandwidth (BW) and SNR (Signal to Noise Ratio) of cellular networks present in heterogeneous environment [20].

$$C = \text{BW} \times \log_2(1 + SNR) \tag{10}$$

ABR of cellular networks present in heterogeneous environment is calculated by using Eq. (11).

$$\text{ABR}_i = \text{BW}_i \times \log_2(1 + SNR_i) \quad i = 1, 2 \tag{11}$$

Table 1
System parameters for simulation model.

S. no.	System parameter	Value
1	Radius of EDGE (R_g)	1000 m
2	Radius of UMTS (R_u)	500 m
3	Path loss exponent of EDGE (γ_g)	3.0
4	Path loss exponent of UMTS (γ_u)	3.4
5	Standard deviation of shadow fading σ_s	8 dB
6	Sampling distance (d_s)	1 m
7	Channel bandwidth of EDGE network	200 kHz
8	Channel bandwidth of UMTS network	5 MHz

where, SNR is the ratio of the transmitted power to the noise power in the received signal. It is measured in dB (decibels) and calculated as follows:

$$\text{SNR}_i = \gamma_i \frac{E_b}{N_0} \quad i = 1, \tag{12}$$

Here E_b is the received energy per bit and N_0 is noise power of the channel. The channel adds white noise with power spectral density N_0 W/Hz and the signal arrives at the receiver at a power level of P watts [21].

Achievable throughput is considered as one more selection metric of proposed network selection model. It is the amount of data moved successfully from one place to another in a given time period [21]. It is measured in bits per second (bit/s or bps). It is affected by the channel environment such as the distance between the transmitter and the receiver, noise, the fading state of the channel and interference power characteristics, packet size, transmission rate and number of overhead bits in each packet, the modulation technique, and the channel conditions. Achievable throughput is calculated by using Eq. (13)

$$T_i = \frac{L-C}{L} \times R_i \times (1 - \text{BER}_i(\gamma_i))^L \quad i = 1, 2 \tag{13}$$

where L is, length of each packet in bits, L is a combination of a payload (K bits) and overhead (C bits). C bits are equal to cyclic redundancy check bits. $K = L - C$. R is data rate and BER is the probability of bit error rate of cellular network present in heterogeneous environment. Probability of bit error rate is calculated by using Eq. (14) which depends upon signal to noise.

$$\text{BER}_i(\gamma_i) = \frac{1}{2} e^{\gamma_i/2} \tag{14}$$

Probability of bit error rate defined in Eq. (14) is for non-coherent FSK in a white Gaussian noise [21].

For numerical computation, the typical values of system parameters falling in the range of practical interest have been taken as shown in Table 1.

In the two cellular environments, different path loss characteristics are chosen. Path loss exponent is lower in EDGE cell, resulting in moderate variation of signal strength with respect to distance as compared to UMTS cell.

4. Proposed network selection criteria

The proposed network selection model formulated a Multiple Attribute Decision Making (MADM) function which evaluates a set of cellular networks in heterogeneous environment. As discussed in earlier section, physical layer metrics are used to perform the network selection. A network selection decision function (NSDF) is defined by using these metrics. The NSDF is an objective function that measures quality of each network at every location while moving from one network to another network. The NSDF is triggered if a new service request is made or a user changes preferences or the MS detects the availability of a new network or there is severe signal degradation or complete signal loss of the current radio link.

NSDF is calculated by using Eq. (15) for cellular networks present in heterogeneous environment.

$$\mathrm{NSDF}(i) = \mathrm{RSS}_i * \mathrm{W}_{i1} + \mathrm{ABR}_i * \mathrm{W}_{i2} + \mathrm{SNR}_i * \mathrm{W}_{i3} + \mathrm{Throu}_i * \mathrm{W}_{i4} + \mathrm{Outage\ Prob}_i * \mathrm{W}_{i5} + \mathrm{BER}_i * \mathrm{W}_{i6} \quad (15)$$

where RSS_i, ABR_i, SNR_i, Throu_i metrics are needed to be maximized and Outage Prob_i and BER_i metrics are needed to be minimized for the always best connection (ABC) in cellular heterogeneous environment as defined in Eq. (16).

$$\mathrm{NSDF}(i) = \mathrm{Maximize} \quad (\mathrm{RSS}_{\downarrow} i * W_{\downarrow} i1[+\mathrm{ABR}]_{\downarrow} i * W_{\downarrow} i2[+\mathrm{SNR}]_{\downarrow} i * W_{\downarrow} i3[+\mathrm{Throu}] \downarrow i * W_{\downarrow} i4) + \mathrm{Minimize} \quad (\mathrm{Outage\ Prob}_i * W_{i5} + \mathrm{BER}_1 * W_{16}) \quad (16)$$

W_{i1}, W_{i2}, W_{i3}, W_{i4}, W_{i5} and W_{i6} are dynamic metric weights of respective cellular network in heterogeneous environment. These dynamic weights must follow the property defined in Eq. (17)

$$\mathrm{W}_{i1} + \mathrm{W}_{i2} + \mathrm{W}_{i3} + \mathrm{W}_{i4} + \mathrm{W}_{i5} + \mathrm{W}_{i6} = 1 \quad (17)$$

Each dynamic weight is proportional to the significance of a metric to the network selection decision. The larger the weight of a specific metric, the more important that metric is to the user and vice versa. PSO algorithm is used to optimize the dynamic weights (W_1–W_6) of proposed network selection algorithm by considering objective function defined in Eq. (16). The computation time constraint of multi-objective PSO algorithm is relatively low and eventually conforms to the multimedia time requirement for reliable communication over wireless network. Several algorithms related to PSO have been proposed in the literature [22–28]. When using PSO, it is possible for the magnitude of the velocities to become very large. Two methods were developed for controlling the growth of velocities. First is to dynamically adjusted inertia factor and second is to use constriction coefficient. So to improve the inertia and convergence of the particle over time, a variant of PSO called as Modified PSO [29] is used, where inertia factor (ω) and constriction coefficient (δ) have been introduced in the velocity update equation respectively.

A large inertia weight (ω) facilitates a global search while a small inertia weight facilitates a local search. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run gives the best PSO performance compared with fixed inertia weight settings. Inertia factor (ω) is multiplied with velocity of particle at nth position to obtain modified velocity update Eq. (18). ω is initialized to 1.0 and is gradually reduced over time.

$$V_{n+1} = \omega * V_n + C_1 * r_1 * (P_{\mathrm{best},n} - \mathrm{Currentposition}_n) + C_2 * r_2 * (G_{\mathrm{best},n} - \mathrm{Currentposition}_n) \quad (18)$$

Constriction coefficient is multiplied with the whole right hand side of the velocity update equation. The modified velocity update Eq. (19) in context of convergence is obtained by

$$V_{n+1} = \delta * \{\omega * V_n + C_1 * r_1 * (P_{\mathrm{best},n} - \mathrm{Currentposition}_n) + C_2 * r_2 * (G_{\mathrm{best},n} - \mathrm{Currentposition}_n)\} \quad (19)$$

where the constriction coefficient (δ) is given in (20)

$$\delta = \frac{2}{|2 - C - \sqrt{C^2 - 4C}|} \quad C_1 + C_2 = C > 4.0 \quad (20)$$

Here C_1 and C_2 are the acceleration coefficients and the values are taken as 2 for easy convergence.

This optimization algorithm has been hybridized with decision making NSDF function and weighing function to achieve better solutions for network selection in heterogeneous environment. Cost function is calculated by using optimized dynamic weights and physical layer selection metrics for cellular networks present in heterogeneous environment by Eq. (21)

$$\mathrm{Cost\ function}(i) = \mathrm{RSS}_i * W_{10} + \mathrm{ABR}_i * W_{20} + \mathrm{SNR}_i * W_{30} + \mathrm{Throu}_1 * W_{40} + \mathrm{Outage\ Prob}_i * W_{50} + \mathrm{BER}_1 * W_{60} \quad (21)$$

where, W_{10}–W_{60} are dynamic metric weights optimized by using modified PSO. The optimum wireless access network selection must satisfy Eq. (22):

$$\mathrm{Optimum\ Network\,(ON)} = \mathrm{MAX}\,(\mathrm{Cost\ Function}\,(1), \times \mathrm{Cost\ Function}\,(2)) \quad i = 1, 2 \quad (22)$$

Network having greater value of cost function is selected as the always best connected network or optimum access network in heterogeneous environment.

5. Performance evaluation

The performance of the proposed algorithm has been evaluated in a scenario when the MS moves with a constant speed along a straight line trajectory between two BSs. It is evident from Fig. 3(a–f) that averaged RSS, ABR, SNR and achievable throughput gradually drops with increase in distance whereas BER and outage probability increases with distance. The above system performance is in close agreement with its desirable behavior as explained in Section 3 which clearly indicates the suitability of modeled system for optimal network selection in cellular heterogeneous environment.

Here, modified PSO has been implemented to optimize the dynamic weights upon locations of the user and its demands to the network to provide best network selection. The impact of increasing the number of iterations on fitness value has been investigated in order to identify the number of iterations required to achieve optima and at the same time conform to the delay constraint for multimedia application. Iterations are varied from 10 to 100, which is based on the fact that no significant variation was observed after 100 successive iterations as shown in Fig. 4(a) & (b) for EDGE and UMTS cellular network respectively. Dynamic optimized weights after 100 iterations for EDGE are 0.4909, 0.0672, 0.0951, 0.1932, 0.0749 and 0.0786 whereas for UMTS network dynamic optimized weights are 0.3211, 0.1686, 0.0917, 0.0169, 0.0557 and 0.1032 for averaged RSS, ABR, throughput, SNR, BER and outage probability respectively.

Performance is evaluated in terms of switching rate, which is defined as the expected number of selections MS experiences while traversing a trajectory from one network to another. This performance measure represents switching load associated with the network selection process. Ideally, there should be one selection across the cell boundary [30]. The switching rate is reduced to 1 by using dynamic weights optimized by PSO as compared to other existing network selection algorithm [30]. Change of state once between cellular heterogeneous networks with respect to distance based on proposed algorithm is shown in Fig. 5. Reduction in switching rate further reduces the signaling overhead on the MS as well as on the network.

The QoS attained for multimedia services by proposed algorithm is evaluated by means of a user satisfaction degree. To compute the user satisfaction, the modified sigmoid utility function is used [31].

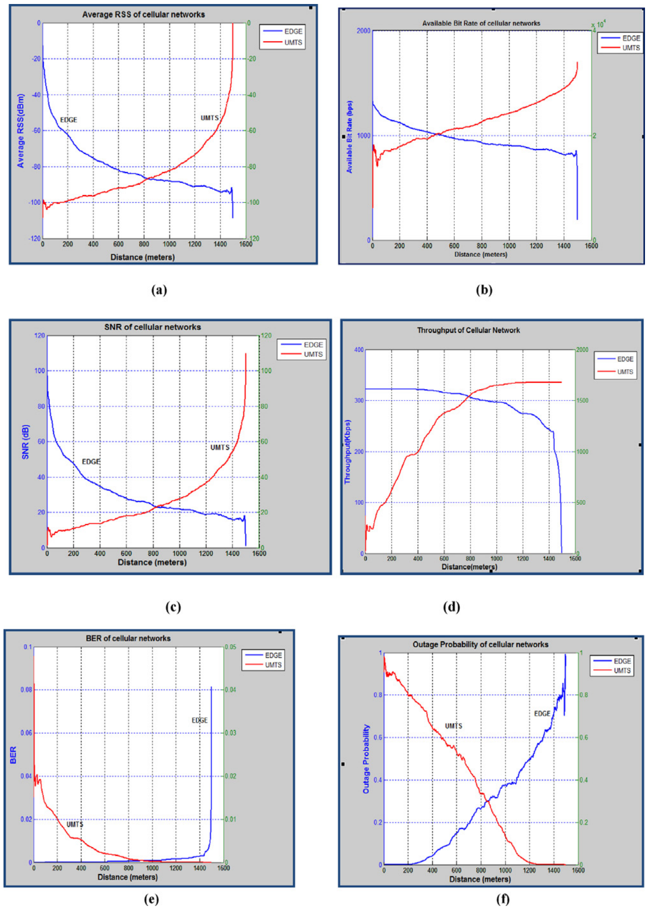

Fig. 3. (a) Average RSS vs. Distance, (b) Available Bit Rate (ABR) vs. Distance, (c) SNR vs. Distance, (d) Throughput vs. Distance, (e) BER vs. Distance, (f) Outage probability vs. Distance in cellular heterogeneous environment of EDGE and UMTS.

Based on the achievable throughput, the user satisfaction degree is given as

$$u_i(T_i) = \begin{cases} 1 & T_i > \eta_i \\ \dfrac{(T_i-\eta_i^{\min})/(0.5\eta_i-\eta_i^{\min})}{1+((T_i-\eta_i^{\min})/(0.5\eta_i-\eta_i^{\min}))} & \eta_1 \geq T_1 \geq \eta_i^{\min} \\ 0 & \text{otherwise} \end{cases} \quad (23)$$

where $\eta_i^{\min}$ is the minimum acceptable bandwidth threshold of MS for multimedia services. The parameter ξ is the tuned steepness parameter which must be $\xi \geq 2$. A user will be completely satisfied if $u_i = 1$ or if user's achievable throughput is greater or equal to user's need i.e., $T_i \geq \eta_i$. User will be considered half satisfied if $u_i = 0.5$ or if user gets only a half amount of throughput

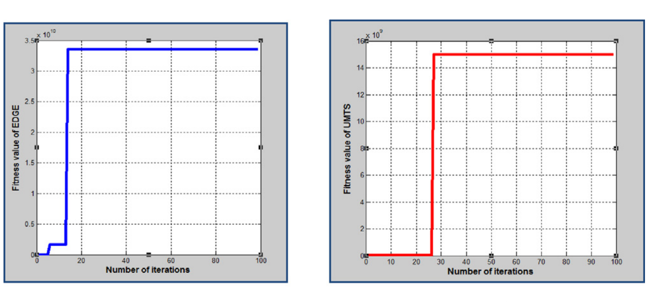

Fig. 4. (a) Current fitness vs. Number of iterations of EDGE cellular network, (b) Current fitness vs. Number of iterations of UMTS cellular network.

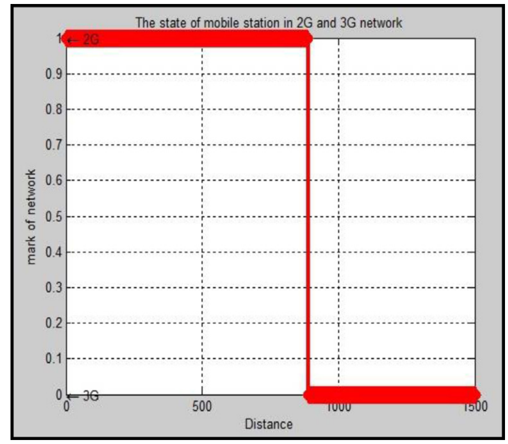

Fig. 5. Network selection between EDGE and UMTS based on proposed algorithm.

that user needs for i.e., $T_i = 0.5\eta_i$. In this simulation, we assume that $\eta_i^{\min} = 64$ Kbps, $\eta_i = 512$ Kbps and $\xi = 3$ for multimedia messaging, web browsing, interactive geographical mapping described in [32]. Fig. 6 represents the utility function of MS of cellular networks in heterogeneous with respect to distance.

It is evident from Fig. 6 that as the distance increases, utility value reduces in cellular networks. EDGE can never attain utility function equal to 1 because it can only support data rate up to 384 Kbps whereas the guaranteed bandwidth requirement of multimedia application is assumed as 512 Kbps. UMTS network can approach utility function equal to 1 because it can support data rate up to 2 Mbps theoretically. Proposed algorithm maintains QoS while selecting ABC network in heterogeneous environment by keeping utility function atleast 0.5. Best QoS can be achieved when achievable throughput is greater than guaranteed required bandwidth or utility function = 1. When network selection is done by using proposed algorithm then utility function is always greater than or equal 0.5.

The proposed algorithm is applied as a part of the algorithm for initial selection of the access network as well as for vertical handover control. Simulation analysis and evaluation of the proposed algorithm with well-known mechanisms in heterogeneous wireless environment have shown that it outperforms other mechanisms, providing always best connected (ABC) network for MS.

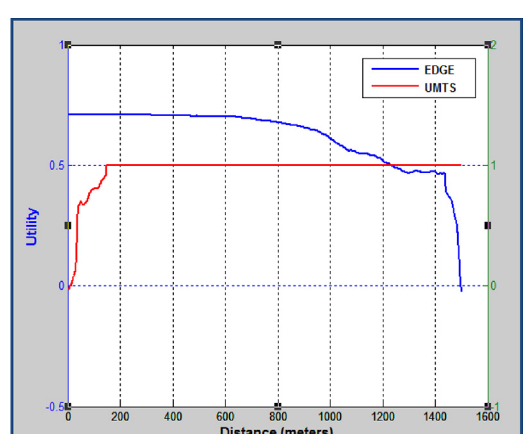

Fig. 6. Utility function vs. distance in cellular heterogeneous environment of EDGE and UMTS.

6. Conclusion

In this paper, we have proposed a new network selection algorithm for heterogeneous wireless environment. The selection decision function is defined as a cost function consisting of six parameters- RSS, SNR, ABR, throughput, BER, and outage probability. Relative weights of the parameters are optimized utilizing modified PSO. Performance of the algorithm is measured in terms of the switching rate of the user between available networks. A utility function derived from the link throughput is also defined to maintain the desired QoS during the transition period of the user. Through numerical results it is shown that the proposed algorithm gives optimum results approaching to single switching from one network to another and is capable to avoid toggling between the different access networks. Moreover, modified PSO has resulted in significantly reduced computational complexity and time. Proposed algorithm has potential applications in multimedia based heterogeneous wireless environment due its high convergence capability and simplicity.

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