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Evaluation of a channel assignment scheme in mobile network systems

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Abstract
The channel assignment problem is a complex problem which requires that under certain constraints a minimum number of channels have to be assigned to mobile calls in the wireless mobile system. In this paper, we propose a new scheme, which is based on double band frequency and channel borrowing strategy. The proposed scheme takes into account factors such as limited bandwidth of wireless networks and the capacity of underlying servers involved in processing mobile calls. It aims to ensure end-to-end performance by considering the characteristics of mobile devices. This is achieved by determining the position of users (or mobile stations) in wireless mobile systems. The proposed scheme is simulated in order to investigate its efficiency within a specific area of a large city in Saudi Arabia. Experimental results demonstrate that the proposed scheme significantly improves the performance of mobile calls as well as reduces the blocking when the number of mobile call increases.

Keywords: Mobile network systems, Channel borrowing, Bandwidth, Dynamic channel assignment

Background
Mobile devices and particularly mobile phones have been used for a variety of purposes ranging from voice calls through to sending SMS/emails to online banking and shopping. Mobile phones generally use cellular network system as one of the main communication network. The rate of increase in the popularity of mobile phone usage has far outpaced the availability of usable frequencies which are necessary for the communication between mobile users and the base stations of cellular networks. This constitutes an important bottleneck in the provided capacity of mobile cellular systems. Careful design of a network is necessary to ensure efficient use of limited frequency resources. One of the most important issues in the design of a cellular radio network is to determine a spectrum-efficient and conflict-free allocation of channels among the cells while satisfying both the traffic demand and the electromagnetic compatibility (EMC) constraints [1]. This is usually referred to as channel assignment or frequency assignment. The problem of channel assignment becomes increasingly important, i.e., how do we assign calls to available channels so as to improve performance and to minimize interference. This paper proposes a new scheme for channel assignment, which is called *Double Band Frequency Channel Borrowing* (DBFCB) scheme. The objective of the proposed scheme is to optimize channel utilization, improve performance and to reduce the blocking probability of calls in a wireless mobile network system.

The proposed scheme is systematically developed and validated through various simulation experiments. It has been applied to the central area of a large city, Madina Monwara, in the Kingdom of Saudi Arabia, using two bands (900, 1800 MHz). Channel borrowing techniques were simulated to investigate the efficiency of this scheme and to make sure that the scheme is viable. The theoretical analysis of the tele traffic was validated through MATLAB simulation analysis [2]. The simulation model is based on the number of users within a specific area which has BTSs. This is based on data collected from the famous local mobile operator, Zain Telecom Company.

The main contributions of the proposed scheme are to reduce the call blocking and call dropping probabilities. Such probabilities generally increase with the increase in the number of mobile users. Thus reduction in call blocking/dropping will enable improved service provisioning in mobile wireless network. In addition, DBFCB algorithm improves response time by using both benchmark and heavy traffic demands with the same known constraints.

The remainder of the paper is structured as follows. "Mobile network architecture and communication" section describes an architecture of a mobile network and a mobile communications process. "Related work" section reviews and analyses related work. "The proposed scheme" section presents the proposed scheme. "Modelling of the proposed scheme" section describes modelling of the proposed scheme. "Experimental results" section describes the experimental results and analysis. "Conclusion" section presents the conclusion.

Mobile network architecture and communication

This section describes the fundamental principles and concepts of wireless mobile network systems. It first presents a generalized architecture of mobile networks and describes its main components. It then describes mobile communications process.

Mobile network architecture

Figure 1 shows an mobile network architecture. The process of call handling in mobile network is carried out in different steps. First, a mobile device (making call) establishes a connection with the access point which is the base station. If the connection is successful the base station responds to the call of mobile device. Radio frequency connection establishment is triggered by sending a channel request message. This message requests the Base station system (BSS) for allocation of radio resources for radio connection setup. The mobile device then waits for an assignment of the access channel. At this point the mobile device is listening to the access channel for a reply. The BSS allocates a channel to the mobile device. This channel allocation assigns a frequency and a timeslot on that frequency. After the mobile device receives this message, it will only use the specified resources for communication within the mobile network.

The main components, of Fig. 1, involved in mobile call handling, are explained as follows.

- *Mobile switching center (MSC)* It provides call control and telephony switching services between telephone and data systems, and it also provides access to the fixed Public Switched Telephone Network. The MSC manages handoff and switching pro-

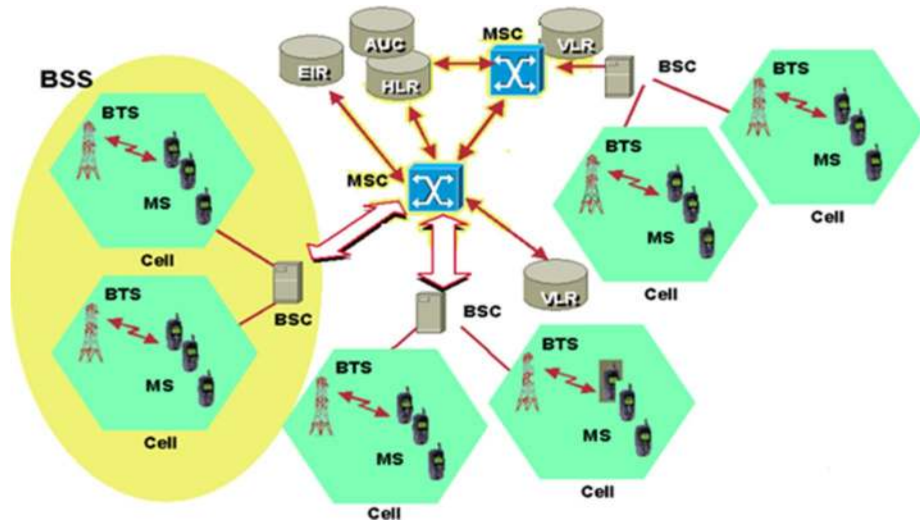

Fig. 1 Mobile network architecture

cesses between cells. It communicates with each relevant BS (Base Station) in order to drop the call from the old BS and to set up a new one in the new BS (as a part of the handoff process). MSCs also orchestrate the process of creating new voice calls. An MS initiates a call by using a reverse control channel to make a request. The MSC has then to grant the request, after which a pair of voice channels is assigned to the call. The MSC includes one database for storing location information and call details of a mobile terminal. The MSC is also connected to a second database in which information about a subscriber registered in its mobile communication service is stored. The base stations route the communications to the MSC via a serving BSC. The MSC routes the communications to another subscribing wireless unit via a BSC/base station path or via the PSTN/Internet/other network to terminating destination. Between MSCs, circuit connections provide the handover mechanism that services calls as users roam from one service zone to another.

- *Home location register (HLR)* It is a central master database within the GSM network, which maintains a permanent store of subscribers' information, and location information for the mobile network. The HLR provides information on the services (subscribed) to the network users. It is also an important source of data to support the roaming process which enables incoming calls that are to be routed to the location of the subscriber.
- *AC or AUC* This is the Authentication Center which contains a secured database handling authentication and encryption keys. It is also a key component of the HLR. It validates the mobile SIM (Security Information Management) card which attempts to connect to a mobile network. It verifies a mobile device by sending a randomly generated number to the mobile device. The mobile device then performs a calculation against it with a number it has stored and sends the result back. If the switch gets the number it expects then the call proceeds. The AC stores all data needed to authenticate a call and to encrypt both voice traffic and signaling messages [3].

- *Base station system (BSS)* All radio-related functions are performed in the BSS, which consists of base station controllers (BSCs) and the base transceiver stations (BTSs) [3].

  - *BSC* It provides all the control functions and physical links between the MSC and BTS. It is a high-capacity switch that provides functions such as handover, cell configuration data, and control of radio frequency (RF) power levels in base transceiver stations. A number of BSCs are served by an MSC.
  - *BTS* It handles the radio interface to the mobile station. The BTS is the radio equipment (transceivers and antennas) needed to service each cell in the network. A group of BTSs are controlled by a BSC.

Mobile communication

Each mobile device uses a separate, temporary radio channel in order to communicate with the cell site. The cell site talks to many mobile devices at once, using one channel per mobile device. Channels use a pair of frequencies for communication (see Fig. 2)—one frequency (the forward link) for transmission from the cell site and one frequency (the reverse link) for the cell site to receive calls from the mobile device. Mobile devices must stay near the base station to maintain communications. The basic structure of mobile networks includes telephone systems and radio services. Mobile radio service operates in a closed network and has no access to the telephone system. But mobile telephone service allows interconnection with the telephone network.

Related work

Various techniques and models have been developed in order to improve the performance of mobile calls and related services in mobile wireless networks. Different factors contribute to the performance aspects such as network traffic, bandwidth, computing

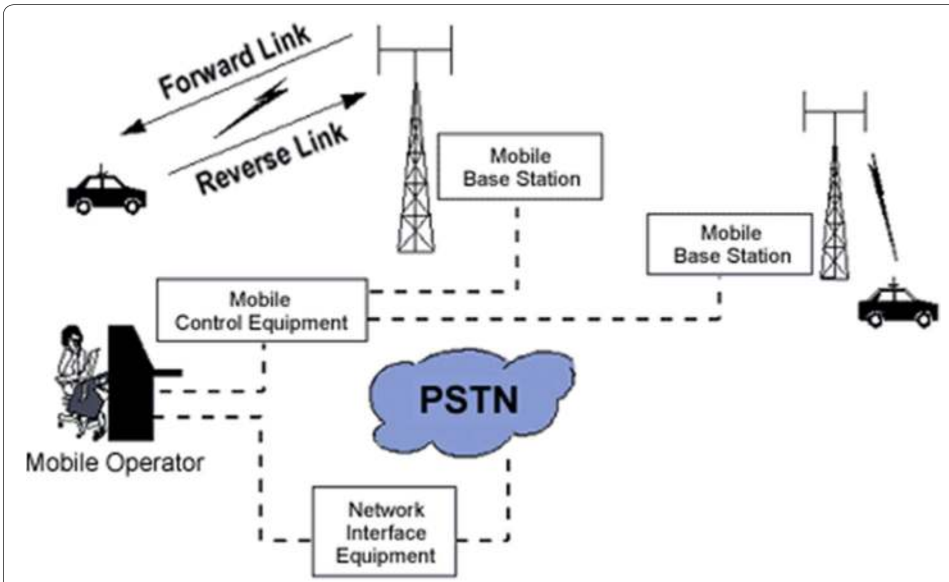

Fig. 2 Mobile communication system

devices, and the wireless signals between the mobile devices and nearby base stations of cellular radio networks.

Various channel assignment schemes have been widely investigated with a goal to maximize the frequency reuse. The channel assignment schemes in general can be classified into three strategies: fixed channel assignment (FCA), dynamic channel assignment (DCA) and the hybrid channel assignment (HCA) [4, 5]. In FCA, a set of channels are permanently allocated to each cell based on pre-estimated traffic intensity. In this case, the co-channel interference (Transmission on same frequency), adjacent channel interference (Transmission on close frequencies), and the co-site channel interference lead to the main problem, i.e., it does not adapt to changing traffic conditions and user distribution. Moreover, the frequency planning becomes more difficult in a microcellular environment as it is based on the accurate knowledge of traffic and interference conditions. The main problem of FCA is the poor channel utilization wherein some users are unable to find any channel to use.

In DCA, there is no permanent allocation of channels to cells. Rather, the entire set of available channels is accessible to all the cells, and the channels are assigned on a call-by-call basis in a dynamic manner. This means that base station chooses frequencies depending on the frequencies already used in neighboring cells. But the issue with the DCA is to handle more traffic in a particular cell [6, 7].

Kyasanur et al. [8] propose to improve the capacity of multi-channel wireless networks. This work exploits multiple interfaces but with the constraint that the number of available channels is greater than the number of available interfaces. It also proposes a strategy that maintains the autonomy of IEEE 802.11 such that it is not required to be modified.

Rajagopalan et al. [9] take into account quality of service parameters such as residual bandwidth, number of subscribers, duration of calls, frequency of calls and their priority. This work is based on the optimization of dynamic channel allocation using genetic algorithm (GA). It attempts to allocate channels to users such that overall congestion in the network is minimized by reusing already allocated frequencies. This work utilizes GA in order to ensure optimization. The optimized channels are then compared with non-optimized channels in order to check the efficiency of the proposed algorithm.

Shindeet al. [10] propose a multi-channel allocation model. It uses an evolutionary strategy with an allocation distance in order to enable efficient use of frequency spectrum. The problem of determining an optimal allocation of channels to mobile users that minimizes call blocking and call dropping probabilities is also emphasized in this work.

In order to ensure efficient and smooth service provisioning in the presence of network congestion, link failures, and mobile service station failures, Boukerche et al. [11] propose that the cellular network be divided into hexagonal cells as shown in Fig. 3. This approach divides the cells into five groups of varying sizes. The request for a channel can be granted if the requesting cell receives the reply from all members of a group. However, this algorithm may not work properly if the replies received by the requesting cell do not satisfy the above mentioned criteria. The algorithm is successful in the scenarios when the area of coverage is divided into hexagonal cells and the reuse distance is fixed for all cells.

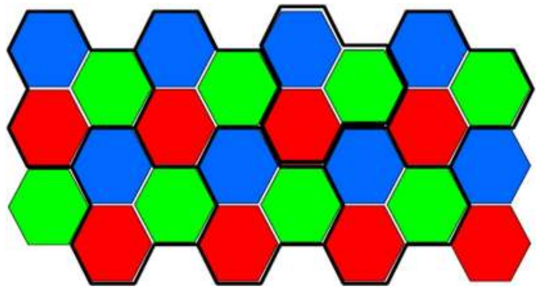

Fig. 3 Frequency reuse (channel allocation)

The proposed scheme

The assignment of channels to cells or mobile devices is one of the fundamental resource management issues in a mobile communication system as it involves different cellular components, handover scenarios, and the complex roles of the base station (BS) and the mobile switching center (MSC). In order to appropriately plan a mobile cellular radio network it is necessary to allocate channels to base stations (BS) so as to ensure that the network can carry sufficient traffic while avoiding interference problem [12].

In a mobile communication system the total number of channels made available (free) to a system depends on the allocated spectrum and the bandwidth of each channel. However, in the current mobile communication system, the available frequency spectrum is limited and the number of mobile users is increasing. Hence the channels must be reused as much as possible in order to increase the system capacity. Thus it is important to allocate channels to cells or mobile devices in such a way so as to minimize the dropping probability of incoming and outgoing calls and the probability that the carrier-to interference ratio of any call falls below a pre-specified value; i.e. the blocking probability which is one of the most important quality of service (QoS) parameters in the channel assignment schemes.

The overall objective is to serve the maximal number of network users over limited transmission resources. The transmission resource is an available radio spectrum which consists of a limited number of frequencies or (channels). Channel assignment problem involves assigning frequencies to each radio cell in such a way that a set of constraints is satisfied [13]. These include the limited number of available frequencies in the radio spectrum as well as the traffic constraints corresponding to the minimum number of frequencies indispensable for covering communication between mobile devices moving in a particular cell. In addition, the electromagnetic compatibility constraints (EMC) may happen between channels in the same cell (co-site channel constraint), interference between neighboring cells (adjacent channel constraint) and interference between other cells utilizing the same channel (co-channel constraint) [14].

This paper proposes a new scheme (or algorithm) in order to optimize the frequency assignment and to enable the reuse of same frequency by sufficiently distant cell. This is to maximize the number of communication (calls) but with a limited number of frequencies. The proposed scheme is called dual band frequency channel borrowing (DBFCB). In Simple Borrowing, channel assignments are borrowed from the adjacent cells and are returned to that cell after it has become free. When a new call initiates and reaches to a cell, and if currently, all the permanent channels allocated to the cell are busy, then channels are borrowed from adjacent cell provided the channels are available (in adjacent cell) and minimum reusable distance constraint is met. In Channel Borrowing algorithms, a database is maintained for the record of channels as per their status either currently in use, borrowed or free. Mobile switch center (MSC), taking care of the channel borrowing activities, runs the channel borrowing procedure, so that channels available are borrowed from the cell having relatively more free channels. Channel borrowing is done under minimum reusable distance constraint. The performance may be reduced for ongoing connections, due to increase of overheads in the base stations of the cellular Mobile system [15].

The main steps of the working mechanism of the DBFCB scheme are illustrated as follows. These steps are diagrammatically shown in Fig. 4.

1. When a mobile user wants to communicate with another user or a base station, it must first obtain a channel from one of the base stations that hears it. That is, when a

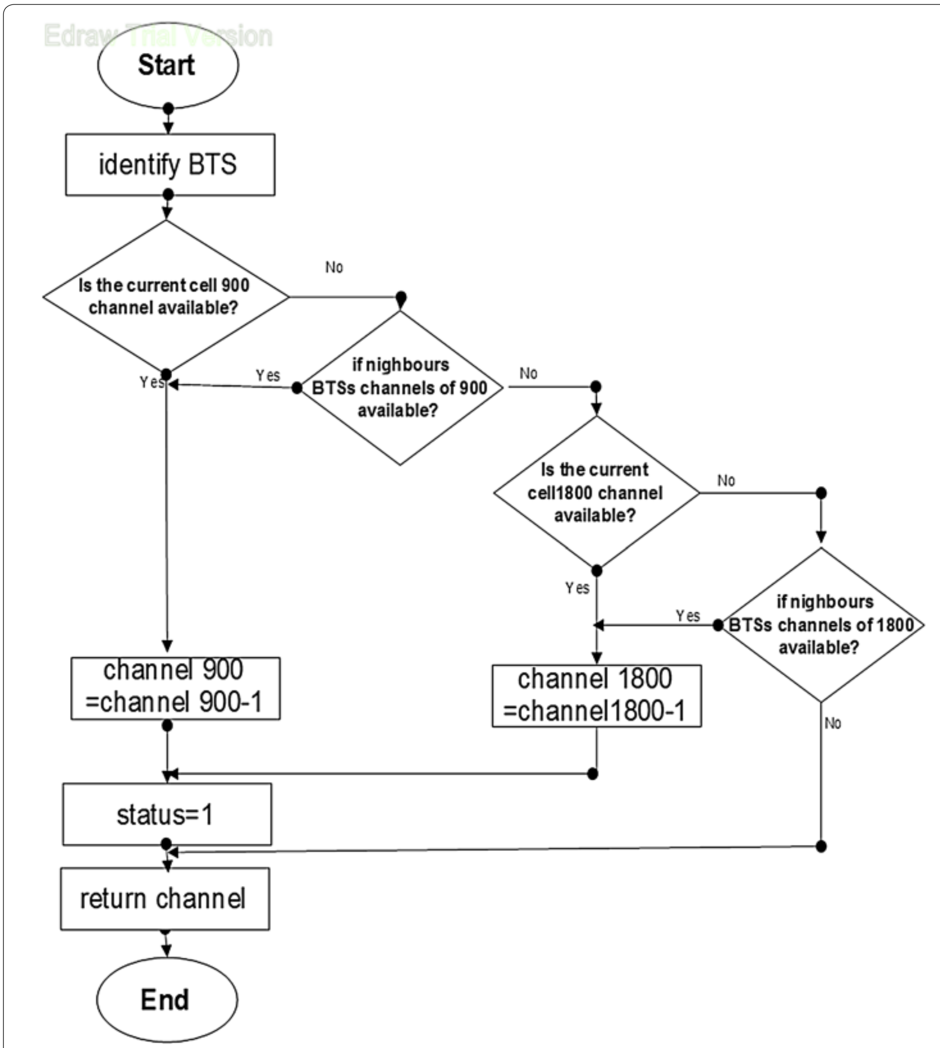

Fig. 4 Flow chart of the dual band frequency channel borrowing (DBFCB) scheme

user (mobile device) wants to starts a call, the base station (BS) is identified [16]. BS is then made aware about user's location.

2. Based on the location, users close to the BS get higher priority compare to users who are away from the BS.
3. When a call request occurs within a cell, the channel allocation (with frequency 900 MHz) of this cell are tested.
4. The channels are tested in an order starting from the first channel of the list. This is to look for the availability of a free channel.
5. If a free channel is found, it is assigned to the call associated with the user (mobile device).
6. If no free channel can be found and all the channels are busy then a channel allocation (with frequency 1800 MHz) is borrowed from the adjacent cell. The adjacent cell is required to have the largest number of channels available for borrowing.
7. If all channels in the adjacent cell are busy then it borrows channels from the next cell (with frequency 1800 MHz), if available.

Modelling of the proposed scheme

This section explains the main elements which are involved in order to model the proposed scheme. Based on these the proposed scheme is then tested and evaluated through simulation experiments [17].

Modelling of the geographical area

In order to test the proposed scheme we model the (simulated) geographical area with respect to a real geographical area of one of the major cities in Saudi Arabia, called Madina Monwara. This city attracts a large number visitors and thus providing a good venue for testing the proposed scheme. It represents the user mobility and traffic behavior within a certain area such as the Haram Area in the city, as shown in Fig. 5. For the proposed scheme, this area represents one cluster (as in related studies of modelling city areas [18]). In line with the related studies, the area under consideration (as in Fig. 5) exhibits specific characteristics such as population distribution, and distribution of MAPs (Movement Attraction Point).

Population distribution Population of people in a geographical area can be grouped into different classes including: visitors, cars, and local working people. The classification

Fig. 5 Geographical area in the city of Madina Monwara, Saudi Arabia

of groups is based on the mobility behavior of a population. However, in the proposed scheme, we consider a representative sample of people which are mobile users (making mobile calls). This is because mobile communication systems focus merely on the mobility behavior of mobile users.

Movement attraction points (MAP) MAPs represent locations that attract the population movements and at which people spend considerable time. Examples are work places, residences, shopping centers, etc. Each MAP characterizes the people group type it attracts. The proposed scheme considers the MAP (shown in Fig. 5) which is the main attraction for visitors in the city of Madina Monwara. Other types of MAPs include residences, work places, shopping centers, etc.

Traffic modelling

We consider the arrival of both incoming and outgoing calls. The call arrival rate refers to the total number of incoming and outgoing calls during busy hour conditions. The call arrival process follows Poisson distribution. For high mobility users, the rate of incoming calls is assumed to be higher than the corresponding outgoing calls.

Consider the scenario in wireless mobile network consisting of two cells in a series. New calls arrive in the first cell with Poisson rate and are served for a time interval that is negative exponentially distributed with mean calls carried in the first cell (block call). After completion of service, calls are offered to the second cell with a fixed handoff probability. These calls are serviced in the second cell for time intervals that are negative exponentially distributed with mean. For simplicity, we assume that cell receives no new calls and also generates no block calls to be given to the first cell. The blocking experienced by the new calls of mobile network in the first cell is given by the Erlang. The traffic load, in Erlang, is the product of the call arrival time and the call duration [19]. The call arrival time represents the cumulative sum of calls inter-arrival time, which follows a Poisson distribution with an average time (λ). Note that we characterize the joint probability distribution of the number of calls in the cells in such a way that we take into account that the users perform random motions. The inter-arrival time define the time period between two consecutive calls.

During the first part of simulation, λ was kept constant in order to investigate the performance at a certain time period with a fixed traffic load. In the second part, the traffic load varied with the simulation time, thus the performance was according to the traffic load. The call duration is chosen as a negative exponentially distributed because for all calls the arrival time and call duration are treated as independent random variables.

Experimental results

The proposed scheme is simulated using the MATLAB software [20]. The simulation model is divided into three parts. The first part deals with simulation parameters, such as the size of simulation area. The second part deals with the traffic generation parameters, such as inter-arrival time, call arrival time, call duration time and random variable generation (e.g., mobile location in the simulation window). The third part deals with the channel assignment mechanism.

Simulation model

The simulation model consists of a fixed window with four-overlapped cells. Each cell consists of two bands frequency, 900 MHz and 1800 MHz. The simulation area is equal to 4 Km^2. Every cell covers 1 Km^2; assume that the cell type used can cover up to 1 Km^2, macrocell. As shown in Fig. 6, the simulation area is divided into four cells, each associated with one BTS (Base Transceiver Station). The coordinates for each BTS are as follows.

- BTS(1) in X-pos starts from 0 to 1000 m and in y-pos from 0 to 1000 m.
- BTS(2) in X-pos starts from 0 to 1000 m and in y-pos starts from 1000 m to 2000 m.
- BTS(3) in X-pos starts from 1000 m to 2000 m and in y-pos starts from 1000 m to 2000 m.
- BTS(4) in X-pos starts from 1000 to 2000 m and in y-pos starts from 0 to 1000 m.

The main parameters considered in the simulation are number of cells, number of channels, population size and the maximum number of iterations.

Simulation results

The proposed algorithm was investigated using four different cases. Each simulation was run ten times in order to obtain an average value in each case.

Case 1 The number of mobile users in the simulation area is 5000 and the channels are 72 in each cell in the entire BTS. The algorithm was investigated under extremely high traffic intensity. The average holding time call was adjusted to 60 s and the average arrival time was adjusted to 1 s. The simulation results are shown in Fig. 7. The blocking call values show that all channels were consumed; i.e., value of channel availability is zero because all channels are busy and there is no free channel at BST. The negative value of channel availability means that new calls have no free channels. The positive value of channel availability means that free channels are available.

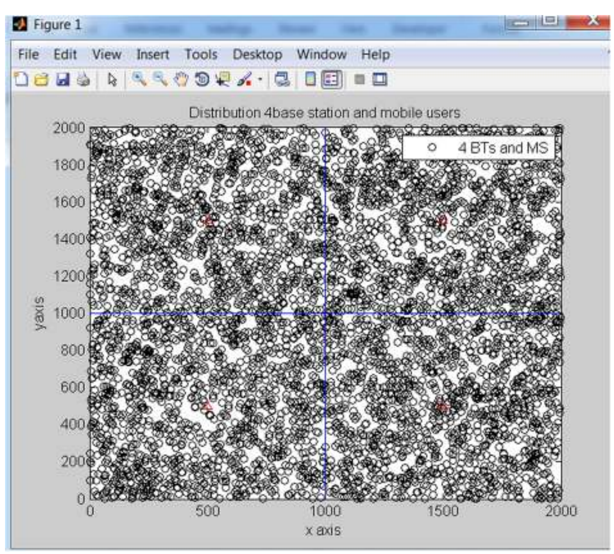

Fig. 6 Distribution of mobile users in the simulation area

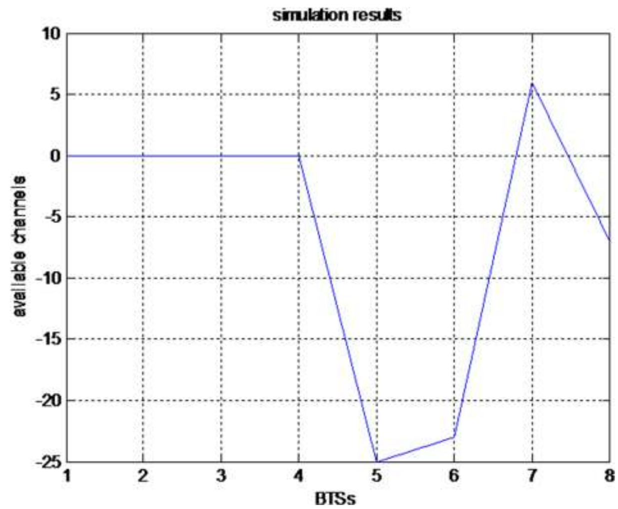

Fig. 7 Channel consumption results at the end of simulation time in case 1

The results show, that in the case of frequency 900 band (1 to 4 BTS) all channels were consumed in 4 Base station that means no free channel (all channels locations were busy in cell) use the other frequency 1800 band.

In the case of frequency 1800 band (5 to 8 BTS), the following observations were made:

(i) BTS 1 consumed all channels and 25 new calls were blocked no channel free available;
(ii) BTS 2 consumed all channels and 23 new calls were blocked no channel free available;
(iii) BTS 4 consumed all channels and 7 new calls were blocked no channel free available;
(iv) BTS 3 consumed 66 channels and 6 new channels were available channel free available.

Case 2 In this case, the algorithm was investigated under high traffic intensity. The average holding time was adjusted to 180 s and the average arrival time was adjusted to 1 s. Figure 8 shows the simulation results:

The results show that in frequency 900 band, all channels were consumed and no channels were free in the band 900 of all 4BTS. In using the other frequency 1800 band, the following observations were made:

(i) BTS 1 consumed all channels and 4 calls were blocked. All channel in this base station are busy and thus 4 new calls were blocked;
(ii) BTS 2 consumed all channels and no free channel was available. All channels were busy in the cell and thus 6 new calls were blocked;
(iii) BTS 4 consumed all channels. 23 calls were blocked as there was no free channel available;
(iv) BTS 3 consumed 59 channels. 7 channels were available channel so calls are not blocked.

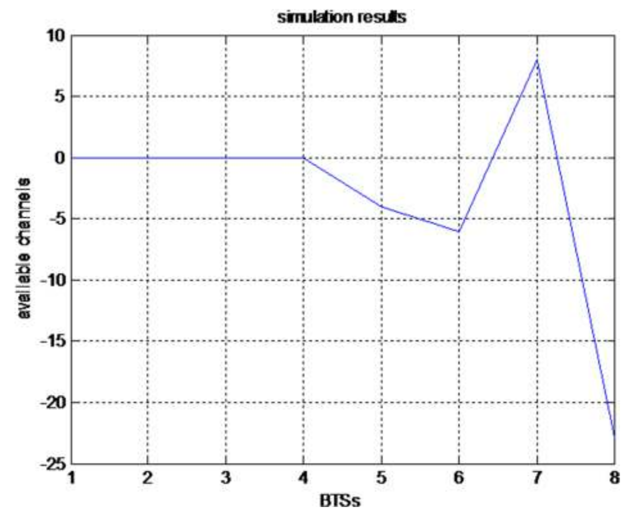

Fig. 8 Channel consumption result at the end of simulation time in case 2

Case 3 In this case, the average holding time was adjusted to 180 s and the average arrival time was adjusted to 30 s. The simulation results are shown in Fig. 9.

The results indicate that in frequency 900 band:

(i) BTS 1 consumed 4 channels and 68 channels are available. Thus no call was blocked;
(ii) BTS 2 consumed 3 channels and 69 channels are available. Thus no call was blocked;
(iii) BTS 3 consumed 4 channels and 68 channels are available. Thus no call was blocked;
(iv) BTS 4 consumed 6 channels and 65 channels are available. Thus no call was blocked.

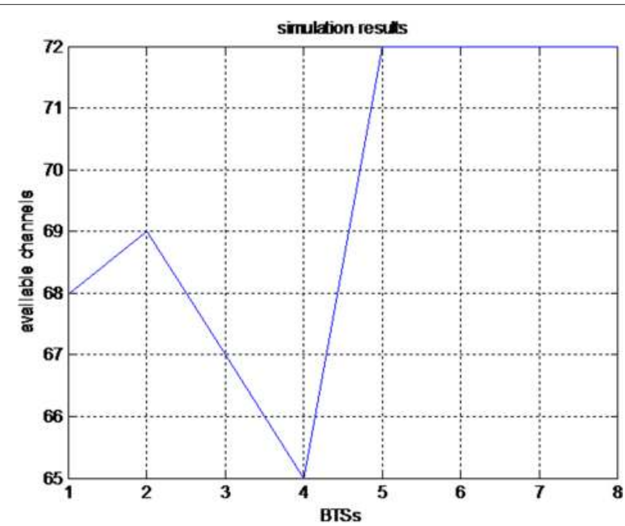

Fig. 9 Channel consumption result at the end of simulation time in case 3

On the other hand, in frequency 1800 band, there were no channels consumed. All channels were available.

The algorithm was investigated under medium traffic intensity. Total channels in each cell were 72.

Case 4 The average holding time was adjusted to 180 s and the average arrival time was adjusted to 120 s. Figure 10 shows the simulation results.

According to the results gathered with frequency 900 band, the following observations were made:

(i) BTS-1 consumed 1 busy channel and 71 channels were available, and no call attempted was blocked;
(ii) BTS-2 consumed 1 busy channel and 71 channels were available, and no call attempted was blocked;
(iii) BTS-3 consumed 2 busy channels and 70 channels were available, and no call attempted was blocked;
(iv) BTS-4 consumed no channel and all channel were available, and no call attempted was blocked;

But in the case of 1800 band there were no channels consumed. All channels were available and no call attempted was blocked. The algorithm in case 4 had lower call blocking as compared to the other cases. This shows the improvement of the proposed scheme in reducing the call blocking.

Conclusion

In mobile network systems, assigning a channel to a call in a cell in order to achieve high spectral efficiency is crucial to maintaining call quality and reducing call blocking. This paper proposed a new scheme in order to improve channel assignment problem in the mobile network systems. The proposed scheme takes into account double

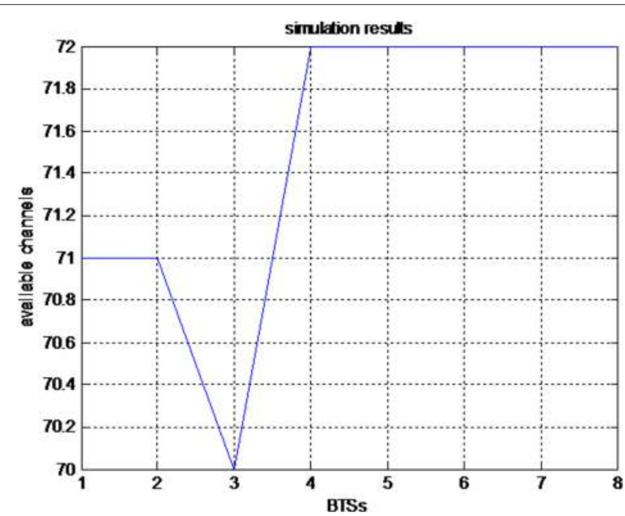

Fig. 10 Channel consumption result at the end of simulation time in case 4

band frequency channel borrowing. It shows greater response to both benchmark and heavy traffic demands and it enhances network performance with optimum load on the network. The algorithm was evaluated using MATLAB that simulated the network and user distribution behavior in a specific (and busy) area of the city of Madina Monwara in Saudi Arabia. Various experiments were conducted. The results showed that the proposed scheme has the capability of reducing the probability of call blocking and call dropping. It also optimizes channel utilization in mobile network systems. The results also show the effectiveness of the algorithm in borrowing and assigning channels in a high traffic intensity and crowded area. Overall the proposed algorithm reduces the blocking rates of calls and improves the response time even under heavy traffic conditions.

Authors' contributions

NN and IN carried out related studies and analysis of the literature. NN, IN and MY participated in the design and development of the proposed scheme which is based on double band frequency and channel borrowing strategy. NN and IN collected simulation data and carried out experiments. MY participated in its design and coordination and helped to draft the manuscript. All authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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