Reliability-Based Channel Allocation Using Genetic Algorithm in Mobile Computing

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***Abstract*—Mobile computing involves bulk data transmission over the transmission media. To achieve highly reliable data transmission, wireless mobile networks require efficient reliable link connectivity, regardless of terminal mobility and, thus, a reliable traffic performance. Mobile networks consist of mobile hosts, base stations, links, etc. that are often vulnerable to failure. It is desirable to design a reliable network, in terms of services of both the base stations and the communication channels of the network, for the reliable transmission of the data. An attempt is made to employ those channels that offer a reliable communication at any given time. The objective of this study is to design an appropriate reliability-based model for channel allocation that retains the overall system reliability with acceptable system performance. The system may achieve acceptable performance not only during normal operations but also under various component failures. A genetic algorithm, which is a search procedure based on evolutionary computation, is suited to solve a class of complex optimization problems. The potential of the genetic algorithm is used, in this paper, to improve the reliability of the mobile communication system. The proposed model designs a reliable mobile communication system, irrespective of the mobile hosts that change their position due to mobility. A simulation experiment to evaluate the performance of the proposed algorithm is conducted, and results reveal the effectiveness of this model.**

***Index Terms*—Byzantine failure, channel allocation, channel reuse, failure, genetic algorithm (GA), handoff, reliability.**

I. Introduction

A CELLULAR system divides a geographical communication area into smaller regions called cells, which are usually hexagonal for analytical and experimental purposes. A typical mobile network environment consists of cells, each of which is serviced by a base station (BS) located at the center of the cell. The BS provides a connection end point for the roaming mobile hosts (MHs). The BS is interconnected by wired or wireless media [1]–[3].

The channel-allocation problem deals with the allocation of frequency channels of the given network to the MHs. Two important concepts in channel allocation are cellular reuse of channels and handoff [1], [2]. The fundamental and elegant concept of cells relies on the channel or frequency reuse, i.e., the usage of the same channel by different MHs separated by a minimum distance [4], without interfering with each other (cochannel interference). Handoff occurs when a user moves from the coverage area of one BS to the adjacent one while it is still involved in communication. A new channel will be assigned to the MHs to continue the ongoing communication. The new channel may be within the same cell (intracell handoff) or in a different cell (intercell handoff). These issues are important in microcellular systems where the cell radius is small [1], [5].

A channel-allocation algorithm consists of two phases: 1) *channel acquisition* and 2) *channel selection*. The task of the channel acquisition phase is to collect the information of free available channels from the interference cells and ensure that the two cells within the minimum reuse distance do not share the same channel. The channel-selection phase deals with the selection of a channel from the available free channels to get better channel utilization in terms of channel reuse [6].

Wireless channels are scant resources, and there is a need to properly manage these resources. Fixed channel allocation (FCA) and dynamic channel allocation (DCA) are well-known channel-allocation schemes. In FCA, the assignment of frequencies to cell is static and does not vary. This approach is easier to implement but is inefficient, because the traffic load varies from time to time. DCA dynamically allocates the channels. One better method, in the case of heavy load on one cell and light load on the neighboring cell, is to borrow channels from the neighbor cells. Cells with heavy traffic are dynamically assigned more channels. This scheme, which is a variant of DCA, is known as borrowing channel allocation (BCA) and is quite common in global systems for mobile communications [3], [4], [7]. However, it requires careful traffic analysis. There are few other ways of dealing with the excess load in mobile networks in addition to channel borrowing, such as channel sharing and cell splitting [8].

The growing importance of mobile networks has stimulated active research into how data can reliably be transmitted over the mobile communication network. This approach suggests allocating channels to the MHs in the presence of various failures in the form of uncertainties. The failure includes signal fading, channel interference, weak transmission power, path loss, etc. This paper suggests a novel idea of channel allocation based on the reliability aspect of the system.

Reliability is the ability of a system to successfully perform its functions in routine and in hostile or unexpected circumstances. Reliability is the probability that the network, with various components, performs its intended function for a given time period when operated under normal (or stated) environmental conditions. The unreliability of a connection is the probability that the experienced outage probability for the connection is larger than a predefined maximum tolerable value. The connection reliability is related to the traffic parameters [9].

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The design of reliable resource-management algorithms for cellular networks is an important issue. Reliability studies for mobile computing are still under extensive research [9], [10]. The design of reliable fault-tolerant bandwidth management algorithms for cellular networks is also an important issue deliberated in [11]–[14]. Thus, the reliability issue is to properly be addressed in mobile computing.

The MH changes its access point time to time. This instance poses several challenges in terms of ensuring system reliability. The increasing reliance on wireless networks for information exchange makes it critical to maintain reliable communications. Even a short downtime may cause substantial data loss; thus, these networks require high level of reliability. Reliability is a crucial parameter, because any failure will not only has direct cost on maintenance but may also result in dropped calls and terminated connection. This condition may be more catastrophic in mobile computing, because it may result in Byzantine failure. Failures that inhibit communications or result in the loss of critical data are of immense importance.

In a wireless cellular network environment, BSs are prone to failure [15]. A BS may either crash or fail to send or receive data. Due to the failure of a BS, all the call connections in the failed cell area get terminated, and all the call services are interrupted until the failed BS is restored. BS failure significantly degrades the performance and bandwidth utilization of the cellular networks. In particular, services for high-priority ongoing calls could be interrupted, which is usually not acceptable. Wireless channels are also inherently unreliable and prone to location-dependent, time-varying, and bursty errors due to noise, multipath fading, shadowing, and interference. Their unreliability is much higher than that of wired links.

The reliability-based channel-allocation model rarely figures in the literature; however, some of the models that address the other reliability issues in cellular networks have been mentioned in brief here. Three cost functions that are associated with the retransmission-based partially reliable transport service were introduced by Rahmi *et al.* [16]. An algorithm for computing low-latency recovery strategy in a reliable network was proposed in [17]. An optimal forward-link power-allocation model for data transmission was proposed in [18]. A soft handoff/power distribution scheme had been proposed for cellular CDMA downlinks, and its effect on connection reliability had been studied by Zhao *et al.* in [9]. A neural-network-based multicast routing algorithm was proposed by Vijay *et al.* [19] to construct a reliable multicast tree that connects the participants of a multicast group. A protocol called the reliable mobile multicast protocol was proposed in [10] to provide reliable multicast services for mobile IP networks. The mobility agent in the mobile IP was extended to assist reliable multicasting for mobile devices.

In recent years, the applications of a genetic algorithm (GA), which is a useful search procedure for optimization problems, have attracted the attention of researchers of various disciplines as a problem-solving tool. The GA is a search procedure based on the natural evolution. The GA has successfully been applied for various optimization problems for which no straightforward solution exists. Researchers of mobile computing have used the GA for channel-allocation problems [7], [20]–[23]. The GA has also been extensively applied for the task-scheduling problem in distributed computing systems [24]–[29].

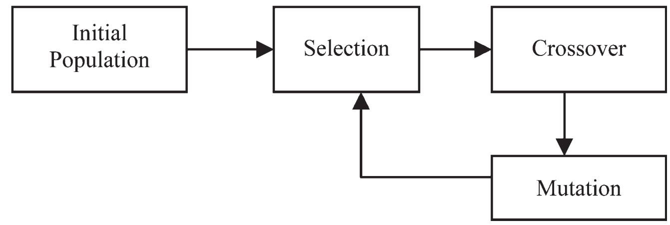

Fig. 1. Operations in the GA.

The design of a reliable fault-tolerant strategy during the design of cellular networks is an important issue and must be considered [13], [14], [30]. Channel allocation based on reliability is an important activity towards this end. This paper discusses the effects of the component failure in mobile cellular networks, with emphasis on improving the reliability that is affected by the users' mobility and the wireless environment. A GA-based reliability model for channel allocation is being proposed here to facilitate wireless mobile network design that meets users' demand in terms of reliable services.

The rest of this paper is organized as follows. In Section II, a brief introduction to GA is given. A fault-tolerant channel allocation (FTCA) model that uses the GA has also been discussed in Section II. The proposed reliability-based channel-allocation model has been described in Section III. In Section IV, the performance of the proposed model is evaluated by carrying out the simulation experiments. Observations based on the results of the experiment on the model and a comparative study are given in Section V, followed by the concluding remarks in Section VI.

II. Genetic Algorithms

The GA is a search procedure based on the principle of evolution and natural genetics. The GA combines the exploitation of past results with the exploration of the new areas of the search space by using the "survival-of-the-fittest" technique combined with a structured yet randomized information exchange. In each new generation, a set of strings is created by using information from the previous ones. Occasionally, a new part is tried from the good measure. The GA is randomized, but it is not a simple random walk. GAs efficiently exploit historic information to speculate on new search points with expected improvement [3], [31], [32].

In GAs, we start with an initial population, which is derived from the solution space. Genetic operators are then applied on the population for the appropriate mixing of exploitation and exploration. A selection strategy is used to carry forward the better population for reproduction. A simple GA consists of an initial population followed by selection, crossover, and mutation operations [31], as shown in Fig. 1.

1) Initial Population: Initial population is the set of potential solutions to the problem. To start with, the number of solutions is generated by using any method (e.g., greedy). Borrowing the terminology from genetic engineering, the population is also called a chromosome or a string. On the initial population, various genetic operators are applied in GA.

2) Selection: The selection operation selects good results among the chromosomes by using some objective function (*fitness function*). The fitness function is used to rank the quality of the chromosomes. A fitness value is assigned to the chromosome, and the chromosome is evaluated with this value for its survival. The fitness of the chromosome depends on how well that chromosome solves the problem at hand. A chromosome (string) with a higher value has a higher probability of contributing to one or more offspring in the next generation [3], [31].

3) Crossover: The idea of crossover is to swap part of the information between a pair of chromosomes to obtain the new chromosome. Simple crossover may proceed in two steps. First, members of the newly reproduced strings in the mating pool are mated at random. Second, each pair of strings undergoes crossing over as follows. An integer position k along the string is uniformly selected at random between 1 and the string length less than one [1, $l-1$]. Two new strings are created by inclusively swapping all characters between positions $k+1$ and l [3], [33].

4) Mutation: In mutation, a chromosome is slightly randomly altered to get a new chromosome. The mutation operator is used to introduce a new genetic material (e.g., 0 or 1). As a result of its generality, it is an insurance policy against the premature loss of important notions. The probability of applying mutation is often very low. Mutation rates are normally small in natural populations [3], [31], [32].

A. GA-Based FTCA Model

The FTCA algorithm in [3] is designed under the *resource planning* model [4], i.e., *primary* channels are initially preallocated to each cell. Furthermore, the *secondary* (borrowed) channels must be returned to the cell from which it has been borrowed as soon as the communication is over.

Each cell has a set of reserved channels (in proportion to primary channels), which will immediately be given to a crossing over MH (to handle handoff). However, at the same time, the cell searches for a new channel. As soon as it gets the new channel, it is allocated to the crossed over MH so that the reserved channel pool is intact.

For experimental purposes, the MHs are randomly distributed among the cells in proportion to the number of channels per cell. It is assumed that the MH movement across the cells is stochastic.

1) Encoding Used: Each cell is represented by a chromosome. A chromosome is an array of length 14. The first location of the chromosome array represents the number of blocked hosts. The second location of the chromosome array is for the number of free channels. The next six locations contain the information about the channel lending to six neighbor cells. The last six locations contain the information about the channel borrowing from six neighbor cells. The chromosome of a cell and the chromosomes of its six neighboring cells form a matrix of $7 * 14$, which is called a superchromosome. Chromosomes are combined into a superchromosome, and all the superchromosomes together give the information of the whole network. All GA operations are performed on the superchromosome.

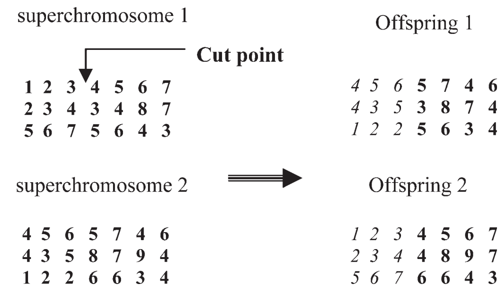

Fig. 2. Crossover operation.

2) Crossover: The crossover operation occurs between two superchromosomes (two matrices) to generate two offspring from them i.e., two new matrices [7]. After this step, we get two new different chromosomes. In Fig. 2, two example superchromosomes are taken, and the crossover operation is illustrated. Crossover site is the cut point in the figure. The example superchromosomes are the reduced ones and are not the same as those used in the model.

III. Proposed Model

In the mobile network, the system is potentially confronted with a wide range of path characteristics to each receiver e.g., different delays, link failure rates, packet losses, and competing congestion on the paths to the different receivers. Different users perceive different channel quality based on their location. The concern here with the link failure rate is in terms of the failure of the BS and channel assigned to the MH for communication.

The work proposed here considers the channel allocation based on the failure rate of the BS and the channel. With the failure of the BS, we mean the total interference level of signals received from the terminal equipment at the BS, the strength of the transmission power, the signal-to-noise ratio between the terminal equipment and the BS, etc. The failure of the channel is determined by the traversal time of a physical path, which is its mean message response time (MMRT). The channel, in fact, is an end-to-end logical entity. The exact physical path for the channel is a random event, because traversals of the intermediate links on the path are instantaneous decisions determined by the data traffic and the node availability, which are random factors [34].

Certain assumptions have been laid down in the model. As with most of the channel-allocation models, cells are assumed to be hexagonal for simplification and analytical reasons. Each cell has one BS that is responsible for allocating the channels for the hosts inside the cell and the crossing-over hosts to this cell. For experimental purposes, MHs are randomly distributed among the cells, depending on the capacity of the cell. It is assumed that the MHs' movement across the cells is stochastic. The channels are assigned to the cells according to the initial requirement of the network traffic. The probability of applying mutation is often very low. The main weakness of mutation in the channel-allocation problem is the taking–borrowing decisions ahead of time that may result in nonoptimality for two reasons: 1) Their effectiveness is not measured in the fitness

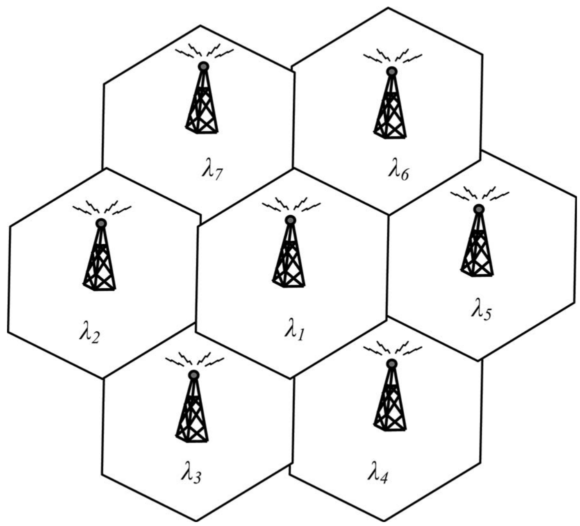

Fig. 3. BSs with different failure rates.

function, and 2) these decisions degrade the future quality of service [3], [32]. Each cell has a set of reserved channels that will immediately be given to a crossing-over MH [3]. The performance of the algorithm is evaluated by measuring the maximum reliability value of the simulated model for the allocation.

The proposed algorithm exploits the potential of the GA to improve the reliability of the communication network system by assigning the channels to the MHs based on the reliability computation. The computation of the reliability parameter depends on two factors: 1) the reliability of the BS and 2) the reliability of the channels. The assignment of the channels to the MHs based on the reliability parameter enhances the overall reliability of the mobile network system.

A. Explanation of the Model

The reliability of the communication session depends on the services of the BSs and the links (channels) over a time T, in which the communication is made between the MHs and the corresponding node. The availability of these services depends on the failure rates of the devices (BS) and the links (channels). As previously mentioned, the failure of the BS is determined by various factors such as the total interference level of signals received from the terminal equipment at the BS, the strength of the transmission power, and the signal-to-noise ratio between the terminal equipment and the BS. The failure of the channel is determined by the traversal time of a physical path, which is its MMRT. We, in this model, have chosen the reliability parameter to be represented by exponential distribution, because the reliability of both the BS and the channel is invariable over the time. This condition means that this entity (BS and channel), which has been in use for some time (any number of hours), is as good as a new entity with regard to the amount of time remaining until the entities fail [35].

The reliability of the BS over time t is $e^{-\lambda t}$, where λ is the failure rate of the BS (see Fig. 3), and t is the time of a session i.e., in which the BS is involved in communication between the terminal devices.

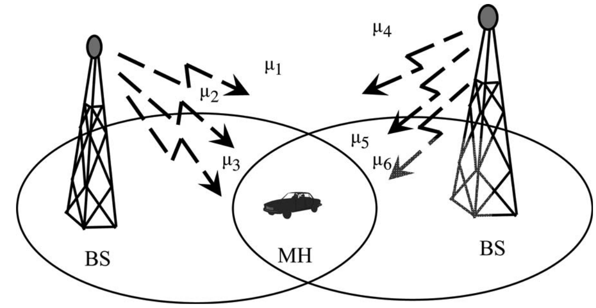

Fig. 4. Network-assigning channels with different failure rates.

If the number of BSs used in the network system for one whole session is m, then the reliability of all the BSs R_B in the network for the session is

$$R_B = EXP\left[-\sum_{k=1}^{m} \lambda_k t_k\right]. \tag{1}$$

This equation is due to the fact that the different BS with different failure rates (λ) are involved over the different time period in one session.

Similarly, if the number of total channels used in one session is n, then the reliability R_C of all these channels for that session is

$$R_C = EXP\left[-\sum_{i=1}^{n} \mu_i t_i\right] \tag{2}$$

where μ is the failure rate of the channel (see Fig. 4).

Note that the total time taken in a session is T and is evaluated as

$$T = \sum_{i=1}^{n} t_i + \sum_{k=1}^{m} t_k. \tag{3}$$

The GA is used as a tool for optimizing (maximizing) the reliability, for both the BSs and the channels, in the proposed model. The population with better reliability value, in each generation, will participate for reproduction in one or more of the next generations.

The model is designed such that, when an MH requests for a channel (for a new or interhandoff call), it is assigned the channels with better reliability estimate. The simulation study is conducted using the channel-allocation strategy developed in the FTCA model [3] but with different objectives. The intrahandoff technique is also considered in the proposed model so that, in the same cell, the channels are reassigned to replace the host's channels by more reliable free channels as and when it is possible.

To observe the effect of communication time on the reliability of the designed network system, an experiment has been conducted for different sessions over the different time periods. An experiment is conducted for the new initiated calls and for the handoff calls.

B. Fitness Function

Based on (1) and (2), the total reliability R_T of the network system for a communication session is given by

$$R_T = R_B \times R_C. \quad (4)$$

To obtain the best reliability for the designed network system, the reliability R_T in (4) will be maximized. This function gives the total reliability of a communication session at any time T.

C. Algorithm

This section proposes a channel-allocation algorithm to optimize the reliability of the network system using the GA. The algorithm uses a channel-allocation strategy similar to the one in [3] with reliability optimization. The algorithm is given as follows.

1. *Input the total number of channels and the MHs.*
2. *Assign channels to each cell based on the initial demand.*
3. *Input generation_no. // for how many generations to carry on the experiment.*
4. *Initialize* $generation\_index = 0$. *// used as the index.*
5. *Initialize* $Max\_system\_reliability = 0$.
6. *Create the initial population.*
7. *Allocate channels to hosts based on the strategy in* [3]. *// see the FTCA model* [3].
8. *Repeat Steps 9–14 until* $generation\_index = generation\_number$.
9. *Perform the genetic operations as in* Section II. *// refer.* [3].
10. *Score the population based on the reliability fitness function. // based on* (4).
11. *Select the best superchromosome as the current superchromosome.*
12. *Output current_ system_reliabilty resulted in the current generation.*
13. *Increment generation_index.*
14. *If* $(current\_system\_reliability > Max\_system\_reliability)$ $Max\_system\_reliability = current\_system\_reliability$.
15. *Output Max_system_reliability.*

The aforementioned algorithm starts with the initialization of the maximum reliability (Max_system_reliability) of the network system to zero. The maximum reliability that is scored based on the fitness function will be the reliability of the system in the current generation, and the best superchromosome will be selected as the current superchromosome. This process is repeated until the algorithm reaches to the last iteration.

Steps 1–7 take a constant time. The complexity of the algorithm depends on the number of iterations and the operations performed within the iteration. The time for the crossover depends on the size of the chromosome and the population size. If the size of the population is n, it will be on the order $\Theta(n)$. Fitness calculation is elementary addition and subtraction; therefore, the time taken in this step is constant. Thus, the complexity of the algorithm will be of the order of $\Theta(nN)$, where N is the number of iterations.

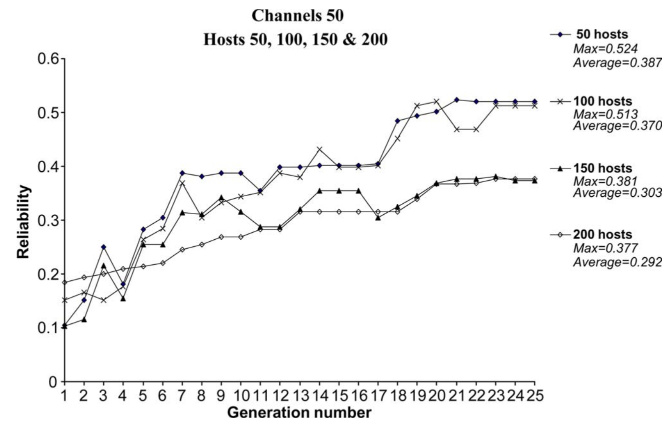

Fig. 5. Fifty channels with varying numbers of hosts.

IV. Experimental Evaluation

In this section, the performance of the proposed algorithm is evaluated. The experiment is conducted up to 25 generations. It has been observed that the solution converges by 25 generations. The experiments have been designed by writing programs in C++.

1) Simulation Parameters: The simulation parameters used in the experiment are listed as follows.

- The simulated cellular network consists of 20 cells.
- The total number of channels and hosts in the network are varying.
- The reserved channels, for all the experiments, are 30% of the total number of channels and are distributed among the cells in proportion to the distribution of the MHs. For example, in the experiments with 50, 100, 150, and 200 channels, the reserved channels are 15, 30, 45, and 60, respectively [3].
- The handoff probability is considered to be 30%, which is in conformity with that of the reserved channels [3].

The results are represented in the performance graphs, where the x-axis represents the generations, and the y-axis denotes the reliability value.

The experiment is conducted for random values (ranges) of BS failures λ and channel failures μ. The maximum value obtained over the generations is taken as the solution. The input values are as follows.

- $\lambda = 0.1 - 0.3$, and $\mu = 0.4 - 0.8$;
- Number of channels: 50, 100, 150, and 200;
- Number of hosts: 50, 100, 150, and 200.

An experiment is performed for various sessions over the different time instances. The graphs for the experiment are shown in Figs. 5–8.

We treat the aforementioned experiment for Session 1. Results that were obtained for Session 1 are summarized in Fig. 9.

Similarly, the experiment is conducted with the same simulation parameters for other sessions (i.e., on different time instances). The results are summarized in the graphs in Figs. 10–12.

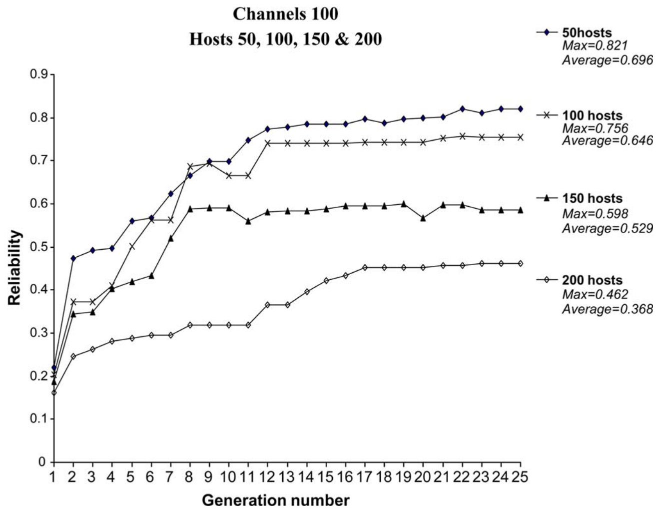

Fig. 6. One hundred channels with varying numbers of hosts.

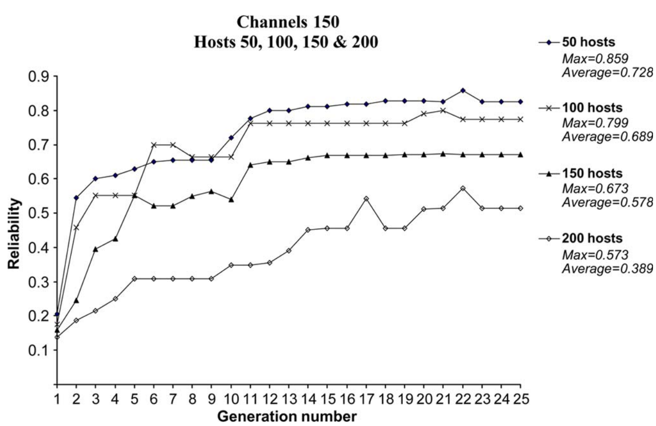

Fig. 7. One hundred fifty channels with varying numbers of hosts.

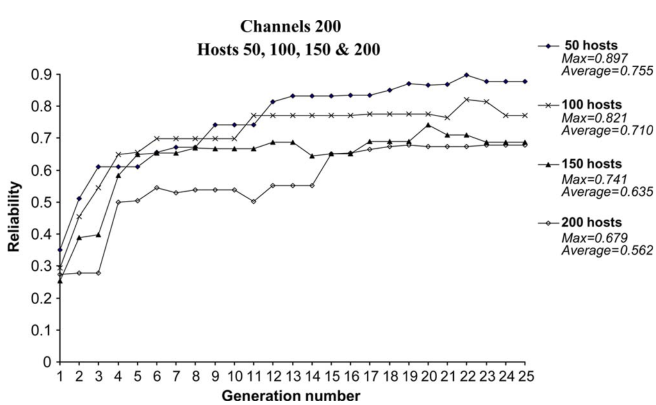

Fig. 8. Two hundred channels with varying numbers of hosts.

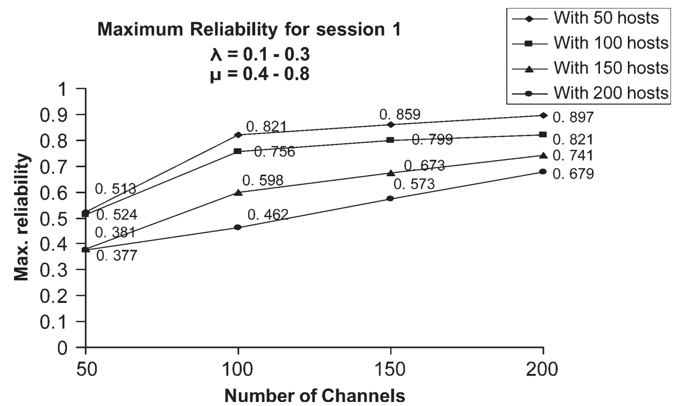

Fig. 9. Results of Session 1.

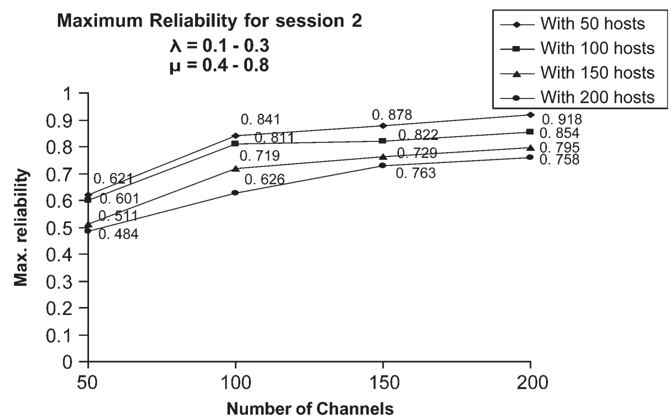

Fig. 10. Results of Session 2.

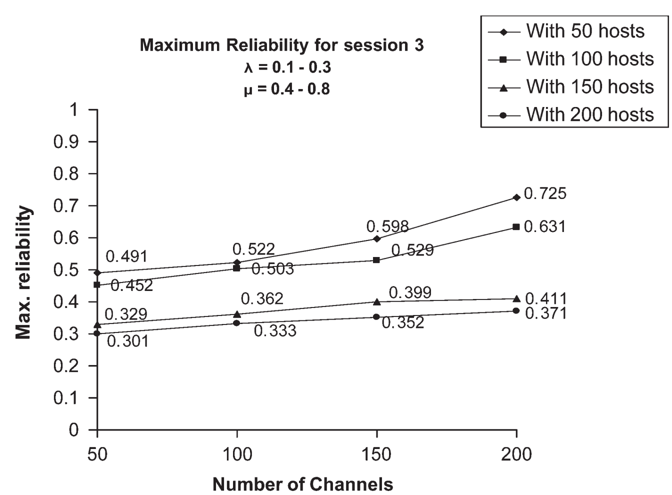

Fig. 11. Results of Session 3.

The average reliability values of all the four sessions are shown in Fig. 13.

Furthermore, we conducted the experiment by varying the values of λ and μ. First, it is conducted when $\lambda = 0.1 - 0.3$ and $\mu = 0.5 - 0.9$. Simulation has been carried out again for the four sessions, and the average value is shown in the graph in Fig. 14.

The next experiment is conducted when $\lambda = 0.2 - 0.4$ and $\mu = 0.4 - 0.8$. The simulation results for the four sessions and the average value are shown in the graph in Fig. 15.

Another experiment is conducted with $\lambda = 0.2 - 0.4$ and $\mu = 0.5 - 0.9$. The average value obtained with the simulation for the four sessions is shown in the graph in Fig. 16.

V. Observations

Before making our concluding remarks, the following observations have been derived from the results obtained in Section IV.

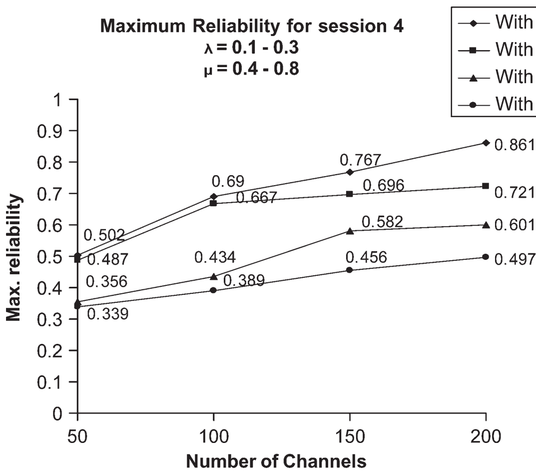

Fig. 12. Results of Session 4.

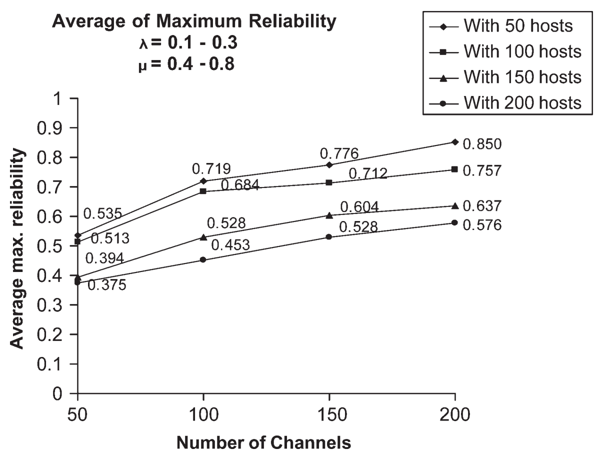

Fig. 13. Average results of the four sessions.

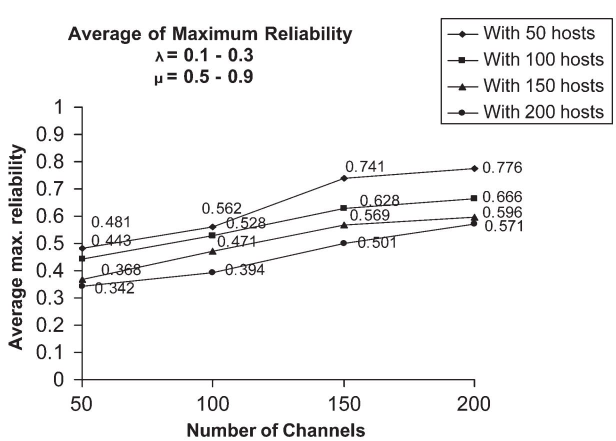

Fig. 14. Average results of the four sessions.

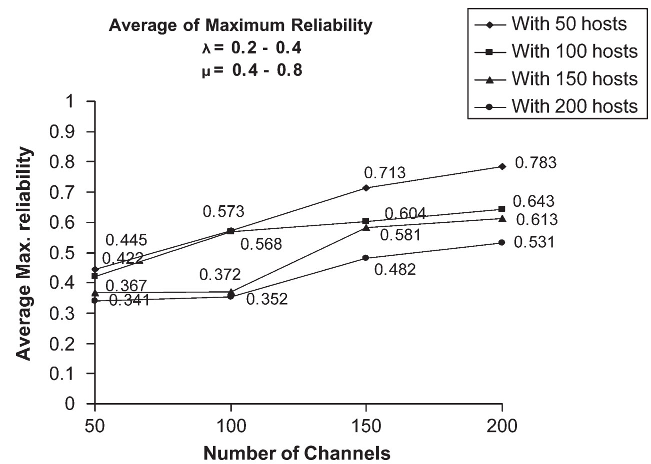

Fig. 15. Average results of the four sessions.

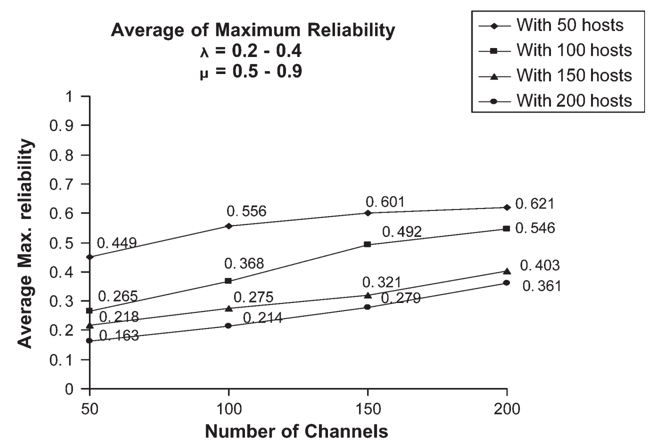

Fig. 16. Average results of the four sessions.

A. Observations

- Both the maximum reliability value and the average reliability value increases over the generations, as shown in Figs. 5–8.
- It is evident that the proposed model increases the network reliability up to 85% and 89% (see Figs. 7 and 8), respectively and, in some sessions, up to 91% (see Figs. 9–16). Thus, in general, the reliability values increase with the proposed model.
- There is an obvious maximization in the reliability values over the successive generations. For example, in Fig. 6, when the number of channels is 100 and the number of hosts is 50, the maximum reliability observed in ten generations is 0.699, whereas for 25 generations, the corresponding result is 0.821.
- Although the channels and MHs are randomly distributed through the cells, and some cells may have fewer channels and more hosts than the other cells, the efficient use of the GA results in better reliability.
- In some cases (e.g., Figs. 5 and 6), although the number of channels is small compared with the number of hosts, good results are still obtained.
- For a fixed range of λ, μ and the number of hosts, the increase in the number of channels results in a corresponding increase in reliability (see Figs. 9–16), because increasing the number of channels gives more chances to fetch better channels.
- Convergence in reliability values is notable when the number of MHs is very high compared with the number of available channels.
- Based on Figs. 9–12, it is clear that, for a fixed range of λ and μ and fixed values of hosts and channels, we observe varying reliability values under various sessions. This case reflects that, on different time instances, we may

get different reliability values, making our inclusion of the exponential distribution model strong.
- It is also notable, for a fixed number of channels and hosts, that the increase in λ and μ results in lower system reliability, which is quite obvious (see Figs. 13–16).

VI. CONCLUSION

In this paper, a reliability-based model that uses the GA to optimize the reliability in mobile computing network has been proposed. The proposed model is an effective approach to make the network connections more reliable. It has been observed that the well-managed and efficient usage of the better channels (with lower failure rates) and delivering them to the MHs greatly increases network reliability. The performance of the proposed model has been evaluated by conducting the simulation experiment. It is found that, over the generations, both maximum reliability and average reliability increase, and the result converges after certain generations. The model cannot be compared with any other method, because no other work conducts the channel allocation based on reliability values. The proposed model can be incorporated with other similar models to increase their reliability and effectiveness. In the future, we intend to observe the effect of increasing the reliability on the other quality-of-service parameters of the network system.

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