A New Quorum System For Fault-Tolerant Channel Allocation In Cellular Wireless Networks

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ABSTRACT: The efficient use of the bandwidth allocated for a cellular wireless network is crucial for the satisfactory performance of the system. In order to increase the channel utilization, the channels are allocated to different cells in a dynamic way. The dynamic channel schemes can be categorized in to centralized and distributed. However, the centralized schemes are neither reliable nor scalable. The issue of fault tolerance is significant in cellular wireless networks because of mobility, poor quality of wireless links and other constraints. Moreover, most of the existing fault tolerant channel allocation algorithms have been designed in such a way that these can be used with hexagonal cells and for the reuse distance of one cell only. Therefore, in this paper, a new quorum system named as neighbor quorum system specifically useful in channel allocation in cellular wireless systems has been proposed. A fault tolerant distributed dynamic channel allocation algorithm using the newly proposed quorum system has also been presented in this paper.

KEYWORDS: Fault-tolerance, channel, quorum, cell, spectrum

I. INTRODUCTION

The bandwidth is a scarce resource in cellular wireless networks and the number of users is increasing at a rapid rate; therefore, the available frequency channels must be used efficiently in order to ensure quality of service (Q.O.S.). A frequency channel can be reused, if the distance between the cells in which the channel is being reused is such that there will be no interference between two cells. The minimum distance which must exist between two cells so that these can use the same channel simultaneously is known as the minimum channel reuse distance.

The channel allocation schemes in wireless cellular networks can be divided in to centralized schemes and distributed schemes [1]. However, due to single point of failure and lack of scalability, the centralized schemes are rarely used. The distributed schemes can be further subdivided in to dynamic schemes, static schemes and hybrid schemes [2].

In static schemes, the channels are statically allocated to each cell. This strategy is simple; however, these schemes exhibit a poor performance if the call distribution is non uniform. In order to solve the problem of non uniform call distribution, dynamic channel allocation schemes were introduced. Dynamic channel allocation schemes assume that any channel can be used by any cell. A combination of static and dynamic channel allocation strategies is used in Hybrid channel allocation schemes in which few channels are statically allocated to cells and rest of the channels are available for dynamic sharing.

The dynamic channel allocation schemes can be categorized in to search based schemes and update based schemes [1]. In search based schemes, a base station needs a channel it searches all neighboring cells to compute the set of currently available channels. In update based schemes, each base station maintains a set of available channels. Each cell informs its neighbors on acquiring and releasing a channel and its neighbors update their respective sets on receiving this information. The search algorithms requires more time in selecting a channel for setting up a call. On the other hand, the number of messages required is much higher in update based schemes in comparison to search based schemes and these messages will also require channel(s) for communication between neighboring base stations.

In the present paper, we propose a search based dynamic channel allocation scheme for cellular wireless networks. The scheme is fault tolerant in the sense that it can tolerate link failure and message failure. The rest of the paper can be divided as follows. The section 2 and section 3 contains the related work and the system model respectively. The new quorum system and its properties have been discussed in section 4. Section 5 and section 6 contains the channel allocation algorithm and its correctness respectively. The fault tolerant capabilities of the proposed quorum system have been discussed in section 7. Section 8 finally concludes the paper.

II. RELATED WORK

In the literature, several channel allocation algorithms have been proposed by the researchers. However, in this section we will discuss only dynamic channel allocation algorithms which are fault tolerant in nature. The first channel allocation algorithm which discussed the issue of fault-tolerance prominently was proposed Prkash-Shivartri-Singhal [3] in 1999. Prakash-Shivratri-Singhal algorithm was simple and efficient. However, it was able to handle the failure of MHs and MSSs. Moreover, they assumed that the failure of MSSs is fail-stop in nature. In 2005, Yang et al. [2] proposed a fault tolerant algorithm for channel allocation which was able to work efficiently even in the presence of network congestion, link failures, and/or mobile service station failures. Yang et al. [2] assumed that the cellular network was divided in to hexagonal cells and the reuse distance was r (the radius of a hexagonal cell). In their algorithm, they divided the 6 cells in to 5 groups of varying size and the request for a channel can be granted if the requesting cell receives the reply from all members of a group. However, this algorithm ceases to work 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 in to hexagonal cells and the reuse distance is fixed to be r (radius of the cell). However, in some cases, it is not practical to divide the area in to hexagonal cells and the reuse distance may also vary. Moreover, the number of messages required to be sent by the cell is equal to all interfering neighbors even in the fault free scenario. The message complexity is not significant when the number of neighbors is small. However, when the reuse distance is large and number of interfering neighbors is more, the message complexity of Yang et al.'s algorithm may affect the performance of the algorithm. Yang-Manivannan [4] presented another fault tolerant which divides the cells in to k disjoints subsets such that the distance between any two cells in a subset is at least the reuse distance. Further, the channels are also divided in to k disjoint group PC_0, PC_1---PC_{k-1}. The channels in PC_i are Primary channels for group I and secondary channels for all other cells. When a cell requires a channel it gives priority to primary channels and tries for secondary channels only if no primary channel is available. Yang-Manivannan [4] used the timeout mechanism for detecting a failure and assumed the reuse distance to be 2D where D is the radius of the hexagonal cell. Boukerche-Abrougui-Huang [5] presented a QoS oriented and fault tolerant channel allocation protocol based upon the mutual exclusion model where the channels are grouped in to 3 equal sized groups and each group of channels cannot be shared concurrently with the same cluster. The algorithm is able to handle MH, BS and communication link failure. In 2007, Chen-Huang [6] presented an adaptive and fault tolerant strategy for channel allocation. The strategy is capable of handling traffic adaptation problem successfully and also achieves some degree of fault tolerance. Kim [7] presented a fault tolerant model for channel assignment in cellular networks using resource channel technique, borrowing/lending and locking techniques. Recently, Cho et al. [8] used eccentric fault tolerant path grouping scheme to achieve the fault tolerance in channel assignment.

III. SYSTEM MODEL

In this paper, we assume that the area covered by the cellular network is divided in to cells, however, these cells are not necessarily hexagonal and not of similar size and shape. In the centre of each cell, there is a BS (base station) which serves the MHs (mobile hosts) present in the cell. The available frequency spectrum is divided in to channels which are further divided in to control channels and communication channels. A communication channel is used for communication between an MH and BS, where as a control channel is used to send control messages required by the channel allocation algorithm. In this paper we preferred search based strategy because of its low message complexity in comparison to the message complexity of update based strategies.

Due to the scarcity of the frequency spectrum, the frequency channels must be used efficiently. Therefore, a frequency channel may be used by two cells simultaneously, if the distance between two cells is more than the reuse distance. Two cells are called neighbors, if the distance between these cells is less than the reuse distance. Hence, two neighbors cannot use the same frequency channel simultaneously.

When a MH wants to communicate, it forwards a request to its BS (via a control channel) then the BS tries to allocate a communication channel to support this communication. If BS has any unused channel, it allocates it to MH. Otherwise, it enters the search mode and tries to borrow a channel from the neighboring cells. If BS fails to allocate a channel to the requesting MH the call fails. If BS does not has any unused channel.

A mobile host can move from cell C_i to cell C_j, this situation is termed as handoff. When a handoff occurs during a call, the mobile host must release the channel acquired in cell C_i and to support this ongoing call, cell C_j must try to allocate a communication channel in order to support this ongoing call. If BS at cell C_j is successful in allocating the communication channel to the moving MH we say that the handoff is successful otherwise the call has to be dropped. In order to reduce the number of calls dropped during handoff, some channels may be reserved for handoff purpose only.

IV. NEIGHBOR QUORUM SYSTEM

Maekawa [9] proposed the use of quorum system in order to reduce the message complexity of mutual exclusion algorithms. Later on, the quorums have been use effectively to achieve the fault tolerant capability in various distributed algorithms for the static distributed systems [10, 11, 12]. As far as the wireless cellular networks are concerned Skawratannanond-Garg[13] used the concept of quorums in channel allocation algorithm in order to reduce the message complexity. However, the algorithm proposed by Skawratananond-Garg [13] was an update based algorithm and because of that the message complexity was still high. Moreover, they assumed hexagonal cells, fixed reuse distance, and six neighbors of each cell and fixed request set.

In this paper, we propose a quorum system which can be used to develop fault tolerant channel allocation algorithm for a cellular wireless network in which the cells are not necessarily hexagonal. Moreover, the quorum system can be designed for any reuse distance.

A quorum system Q, also referred as *coterie*, is a set of quorums satisfying following two properties:

a) Intersection: $\forall Q_i, Q_j \in Q \rightarrow Q_i \cap Q_j \neq \emptyset$

b)Minimality:

$$\forall Q_i, Q_j \in Q \;\&\; Q_i \neq Q_j \rightarrow Q_i \text{ is not a subset of } Q_j$$

The use of quorum system helps in reducing the message complexity in distributed mutual exclusion and other problems because a requesting node need not to send the request message to all the nodes of the system but to the members of the selected quorum the size of which is $O(\sqrt{n})$ if designed properly. Moreover, the quorum system helps in achieving fault tolerance, since, if a member of the selected quorum fails to respond the requesting node may select another quorum from the system.

Let $IN(C_j)$ be the set of interfering neighbors of a cell C_j then a quorum system C for cell C_j is a set of subsets of $IN(C_j)$. Let $C= \{Q_1,Q_2….\}$. In addition to the above mentioned conditions the quorum system must satisfy the following additional property (named as neighbor covering property) before it can be used in a channel allocation algorithm:

$$\forall Q_i \in C \rightarrow IN(Q_{i1}) \cup IN(Q_{i2}) \ldots = IN(C_i) \text{ where } Q_{i1}, Q_{i2} \ldots \text{are the members of } Q_i$$

The neighbor covering property ensures that if a base station C_j requiring a channel receives permission from all members of quorum Q_i satisfying the neighbor covering property that means that all interfering neighbors of C_j does not have any problem in fulfilling the request of C_j.

The proposed quorum system can be utilized for designing fault tolerant channel allocation algorithms in cellular wireless networks with arbitrary cell shapes and arbitrary reuse distance. The requesting cell may borrow a channel even if it does not receive reply from all its neighbors till it receives reply from all members of a quorum. This is a generalization of the idea of the group proposed by Yang-Jiang-Manvinnan [1] which can only be applied for hexagonal cells and a fixed reuse distance. In the next section, it has been shown how the proposed neighbor quorum system can be used in channel allocation. Moreover, the new quorum-based algorithms with better message complexity and fault-tolerant capabilities may also be designed using the neighbor quorum system.

V. ALGORITHM

In this section, we present the brief description of a search based algorithm using neighbor quorum system for channel allocation in cellular wireless system. To the best of our knowledge, the quorum systems have not been used in search based algorithms for channel allocation by the researchers till date. The brief description of the algorithm is given below.

When a call is generated in a cell C_i, it first checks whether any channels allocated to C_i is available, if such channels exists it select a channel from these channels. Otherwise, the cell enters in search mode, sends a request message to all its neighbors and sets a timer. Now, there are following two possibilities:

(a) C_i receives replies from all its neighbors: In this case, C_i calculates the set of channels which have not been allocated to any of its neighbors or itself, if such channels exist; it selects a channel from this set and adds this channel to the list of its allocated channel. Otherwise, it tries to find the set of channels which have been allocated to one of its neighbors but not in use currently. If this set is not empty, C_i selects a channel from this set and consults with the cell C_j to which the selected channel was previously allocated and use the selected channel on receiving permission from C_j. However, if both the above mentioned sets are empty, C_i drops the call.

(b) C_i did not received replies from all neighbors: On expiry of timer, if C_i has not received reply from all of its neighbors, it may still be able to borrow a channel from its neighbors provided that the following condition is satisfied.

Let R be the set of neighbors from which the cell C_i has received reply on expiry of timer.

If $\exists Q_i \in C \rightarrow \quad Q_i \subseteq R$ then C_i is still able to borrow a channel from neighbors provided that there is a set of channels that have been allocated to all members of Q_i but is not being used by any member of Q_i. Q_i selects a channel from this set, however, before using this channel C_i has to consult all members of quorum Q_i because any member of Q_i may start using this channel just after sending the reply to C_i. Therefore, C_i can only use this channel after all members of Q_i confirms that they are still not using this channel and allows C_i to use the selected channel. If C_i fails to receive permission from all members of Q_i, it selects another channel from the set if such a channel exists. Otherwise, C_i tries to find another quorum Q_j satisfying the above mentioned condition. However, C_i drops the cells when all possibilities are exhausted.

When a cell C_i receives a request from cell C_j, it immediately sends its channel uses information to C_j, if C_i is not in search mode or its priority is lower than that of C_j's priority (Priorities may decided using Lamport's logical time stamps [14]). A cell can allow several borrowers' request for the same channel concurrently provided that no two of them are neighbors. Once a cell has allowed to requesting cell (s) for a particular channel, it can no longer use this channel for its own purpose and the borrower does not return the channel to the lender.

VI. CORRECTNESS PROOF

Lemma: Two cells are not allowed to borrow the same channel if these are neighbors.

Let us assume the contrary that two cells C_i and C_j have successfully borrowed a channel n_k. Now, there are four following four possibilities:

(a) C_i and C_j have received reply from all neighbors: In this case, C_i must have received reply from C_j and C_j must have received reply from C_i. However, due to the priority scheme only one of these two events is possible; hence case (a) is not possible.

(b) C_i has received reply from all neighbors and C_j has received reply from a quorum Q_i.Since, C_i has received reply from all neighbors; it must have received reply from C_j also. However, C_j will allow C_i to use the channel n_k only when it is not using n_k. Therefore, case (b) is not feasible.

(c) C_j has received permission from all neighbors and C_i has received permission from a quorum Q_i: Similar to case (b).

(d) C_i has received permission from all members and channel n_k is allocated to all members of Q_l as well as that of Q_m. Since, C_i and C_j are neighbors C_j there will be a common member in Q_l and Q_m and this common member is aware that C_i and C_j are neighbors. Therefore, this common member of Q_l and Q_m will permit only one cell to borrow the channel n_k. Therefore, case (d) is also not possible.

Our assumption is wrong in all the four cases; hence, it is proved that two cells are not allowed to borrow the same channel, if these are neighbors.

VII. FAULT TOLERANT CAPABILITIES

The communication link in wireless systems are more error prone in comparison to static wireless systems. Therefore, the fault tolerant capabilities are more relevant in wireless systems. In search based algorithm, Yang-Jiang-Manvinnan [1] used the concept of group in order to allow a cell to borrow a channel even if it has not received the replies from all neighbors. However, there approach is specific to the networks in which cells are hexagonal in nature and reuse distance is R (where R is the radius of a hexagonal cell).

It is not always possible to divide the cellular networks in to hexagonal cells of equal area. For example, in urban areas the number of users per unit is much higher in comparison to rural areas. Therefore, the area of rural cell may be larger than the area of an urban cell. Additionally, the cells may not be actually hexagonal because of geographical problems. Hence, in the present paper we proposed a quorum system which can be used for any shape (or irregular shape) of cells and for any reuse distance. Moreover, the quorum system is deadlock free because of the intersection property and provides low message complexity.

The fault tolerant capability of neighbor quorum system comes from the fact that a cell C_i is successfully available to borrow a channel from its neighbors even if some replies are lost due to communication link failure or base station failure. A cell is able to borrow a channel correctly, if it has received replies from all members of a quorum (say Q_l). This is because of the neighbor covering property added to the neighbor quorum system which requires that the quorum Q_l covers all interfering neighbors of the cell C_i.

VIII. CONCLUSIONS AND FUTURE WORK

In the present paper, we presented a quorum system named as neighbor quorum system specifically designed for solving channel allocation problem in cellular wireless networks in a fault tolerant manner. The main advantage of using the neighbor quorum system is that it can be used with any shape of cells and with any reuse distance. An algorithm using neighbor quorum system has also been presented. As a future work we are planning to develop new search based channel allocation algorithms with lower message complexity and compare their performance with the existing algorithms.

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