Handover and Channel Assignment in Mobile Cellular Networks

Quick and timely handover has a crucial effect on how users perceive quality of service, however, handover strategies should not be too complicated.

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The rapid growth in the demand for mobile communications has led the industry into intense research and development efforts towards a new generation of cellular systems. One of the important objectives in the development of the new generation is improving the quality of cellular service, with handovers nearly invisible to the Mobile Subscriber (MS). In general, the handover function is a most frequently encountered network function and has direct impact on the perceived quality of service. It provides continuation of calls as the MS travels across cell boundaries, where new channels are assigned by the new Base Station (BS) and the Mobile Switching Center (MSC).

The system performance characteristics include probability of blocking of new traffic, probability of forced termination of ongoing calls, delay in channel assignment, and total carried traffic. There is a tradeoff between the quality of service and implementation complexity of the channel allocation algorithms, number of database lookups and spectrum utilization. In selecting a channel assignment strategy, the objective is to achieve a high degree of spectrum utilization for a given quality of service with the least possible number of database lookups and simplest possible algorithms employed at the BS and/or the MSC. Handover prioritization schemes are channel assignment strategies that allocate channels to handover requests more readily than originating calls. Prioritization schemes provide improved performance at the expense of reduction in the total admitted traffic.

In this article, we provide a taxonomy of the channel assignment strategies along with the complexity in each cellular component. Next, we consider various handover scenarios and the roles of the BS and MSC. We then discuss the prioritization schemes and define the required intelligence distribution among the network components.

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Strategies and Functionality

Efficient utilization of the scarce spectrum allocated for cellular communications is certainly one of the major challenges in cellular system design. All of the proposed strategies suggest the reusage of the same radio frequencies in noninterfering cells. Channel assignment strategies can be classified into fixed [1], flexible [2] and dynamic [3] (see Fig. 1). Table 1 provides a summary of these strategies, along with the role assumed by the MSC with each of them. The MSC function common to all channel assignment strategies is the storage and update of information on which MS is being served on which channel. This information is essential for network-directed criteria (involved in other network functions as well) such as location information of MSs, control traffic loads and overall traffic loads. In the descriptions of various channel assignment strategies that follow, we focus on the case where all cells under consideration belong to the same MSC.

Fixed Channel Assignment Strategies

The common underlying theme in all fixed assignment strategies is the permanent assignment of a set of channels to each cell. The same set of radio frequencies is reused by another cell at some distance away. The minimum distance at which radio frequencies can be reused with no interference is called the "cochannel reuse distance," which is accepted to be three cell units in the seven-cell cluster model.

The basic fixed assignment strategy (see Fig. 2) implies that a call attempt at a cell site can only be served by the unoccupied channels of the predetermined set of channels at that cell site; otherwise, the call is blocked. Here, the only role of the MSC is to inform the new BS, and receive a confirmation or rejection message from the new BS, about the handover. The MSC keeps track of serving channels for the purpose of updating stored information regarding the location of the MS.

Other fixed assignment methods are variations of the basic strategy described above, with various channel-borrowing methods (see Fig. 3). We will demonstrate the role of the MSC with the simple borrowing, hybrid assignment, and borrowing-with-channel-ordering strategies.

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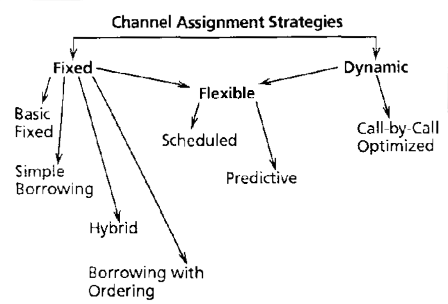

Figure 1. Classification of channel allocation strategies

In the simple borrowing strategy, if all permanent channels of a cell are busy, a channel can be borrowed from a neighboring cell, provided that this channel does not interfere with the existing calls. When a channel is borrowed, additional cells are prohibited from using it. The MSC supervises the borrowing procedure, following an algorithm that favors channels of cells with the most unoccupied channels to be borrowed. The algorithm "locks" the borrowed channel toward the cells that are one or two cell units away from the borrower cells. The MSC keeps record of free, serving and borrowed (therefore, locked) channels and informs all involved BSs about locked channels. The reward of increased storage requirement at the MSC and the need for database lookups is a lower call blocking probability up to a certain traffic level. In heavy traffic, since borrowed channels are locked for at least five additional cells, channel utilization efficiency is degraded.

This trend is improved by the hybrid channel assignment strategy proposed in [4]. In this strategy, permanent channels of a cell are divided into two groups: one group can be used only locally, i.e., within the cell; the other can be borrowed. The ratio of the numbers of channels in the two groups is determined *a priori*, depending on an estimation of the traffic conditions. In addition to its duties in the simple borrowing strategy, in the hybrid channel assignment strategy, the MSC has to label all channels with respect to the group to which they belong.

The borrowing-with-channel-ordering strategy suggested in [5] introduces a further improvement on the channel-borrowing concept. It elaborates on the idea of hybrid assignment by dynamically varying the local-to-borrowable channel ratio according to the changing traffic conditions. Each channel has a different adjustable

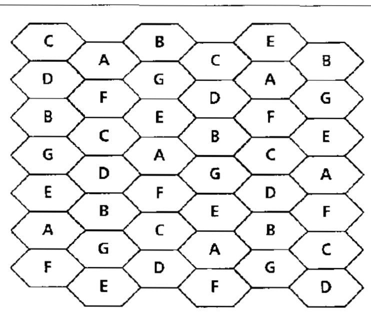

Figure 2. Fixed channel assignment strategy. A - G denote different sorts of channels permanently assigned to cells

Channel Assignment Strategy	MSC Functionalities
Fixed Assignment	Inform new BS Keep track of serving channels
Simple Borrowing	Keep track of free/serving/locked channels Inform all involved BSs
Hybrid Assignment	Assign a set of fixed and borrowable channels to each cell at an optimum ratio depending on estimated traffic load Keep track of free/serving/locked channels Inform all involved BSs
Borrowing with Channel Ordering	Adjust fixed/borrowable channels ratio according to traffic load to each channel Assign a probability of being either used for a local call or borrowed Keep track of free/serving/locked channels Inform all involved BSs
Flexible (Scheduled)	Assign flexible channels at scheduled time according to stored estimation pattern Keep track of free/serving/flexible channels
Flexible (predictive)	Assign flexible channels according to changing traffic Keep track of free/serving flexible channels
Dynamic (Call-by-Call)	Assign channels upon request by evaluating channel reuse distance and future call blocking probability Keep track of free/serving channels

Table 1. MSC roles with different channel assignment strategies

probability of being borrowed and is ranked with respect to this probability, so that channels toward the bottom of the list are more likely to be borrowed, and vice versa. Each time a call is attempted, an algorithm at either the MSC or BS is run to choose the most "appropriate" channel among all free channels, looking at their associated probabilities. If this is part of the BS functionality, the MSC must be informed of the resulting assignment. The MSC determines and updates each channel's probability of being borrowed, based on the traffic conditions, by using an adaptive algorithm. The channel assignment strategy can be made more complex by allowing intracellular handover, i.e., immediate reallocation of a released higher-rank channel to a call existing on a lower-rank channel. The aim of such reallocation is to minimize the number of calls on the relatively more "borrowable" channels in order to reduce the locking effect of borrowed channels in additional cells. Reallocation is achieved by a comparison algorithm accommodated at either the BS or MSC, which is invoked each time a channel is freed.

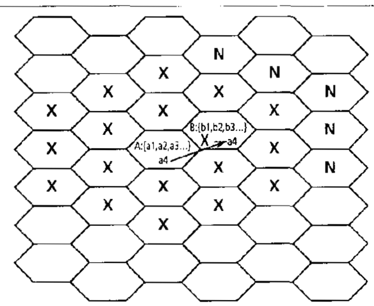

Figure 3. Borrowing strategies. Channel a4 is borrowed and now locked to cells marked "N." Cells marked "X" were already prohobited from using a4.

Dynamic Channel Assignment Strategies

In contrast to fixed assignment, in dynamic assignment strategies cells have no channels to themselves but refer all call attempts to the MSC, which manages all channel assignment in its region. Each time a call attempt arrives, the BS asks the MSC for the channel with the minimum cost to be assigned. The cost function depends on the future blocking probability, usage frequency of the candidate channel, the reuse distance of the channel, and so on. The MSC decides, on a call-by-call basis, which channel to assign to which call attempt by searching for the available channel for which the cost function is minimum. It needs to have information regarding channel occupancy distributions under current traffic conditions and other network-directed criteria, as well as radio channel measurements of individual MSs.

Flexible Channel Assignment Strategies

Flexible channel assignment strategies combine aspects of both the fixed and dynamic strategies in the sense that each cell is assigned a set of permanent channels that typically will suffice under light traffic loads. The MSC holds a set of flexible channels and assigns these to cells whose permanent channels have become inadequate under increasing traffic loads. The distribution of these emergency channels among the cells in need of them is carried out by the MSC in either a scheduled or predictive manner [2].

If the flexible channels are reassigned on a scheduled basis, it is assumed that future changes in traffic distribution are pinpointed in time and space. The change in assignment of flexible channels is then made at the predetermined peaks of traffic change.

In the predictive assignment strategy, the traffic intensity or, equivalently, the blocking probability, is constantly measured at every cell site so that the reallocation of the flexible channels can be carried out by the MSC at any point in time.

Flexible assignment strategies, like call-by-call dynamic strategies, require the MSC to have up-to-date information about the traffic pattern in its area and other network-directed criteria in order to manage its set of flexible channels efficiently.

Possible Handover Scenarios

The channel assignment strategies described above are used whenever a new call or handover request is received by the BS or MSC. Some assignment strategies prioritize handover requests in order to protect ongoing calls from forced termination. Before describing the handover prioritization schemes, we review the handover process (see Table II).

The decision that a handover shall take place can be made by both the MS and the BS by monitoring the channel quality. If the decision is made by the MS alone, a handover request is provided to the BS. The new BS is determined by the MS or MSC. If it is determined by the MS, the candidate BS is provided to the MSC. We note that the decisions made by the MS are based on radio channel measurements only, whereas the MSC is in a position to judge according to a collection of criteria, including network-directed ones such as the traffic distribution in the area.

Radio Channel Measurements

From the viewpoint of the network, the detection of the need for handover and its timely execution are challenging tasks. Momentary fadings in the communication channels between the MS and BS may occur due to geographical and environmental factors well within the cell. This means that the decrease in the power level of these channels should be observed for a certain amount of time before it can be concluded that the MS is actually moving away from the BS. On the other hand, if there actually is a need for handover, it must be responded to as soon as possible in order to minimize the risk of forced termination of the call. In order to detect the need for handover, the MS needs to take measurements on the channel it is currently using as well as the broadcast channels of the neighboring cells. Different standards for cellular operations specify different procedures for these

Task	MS	BS	MSC
Radio Channel Measurements	Make periodic measurements on current and neighboring broadcast channels Send results to BS		
	Start measurements Send results to BS	Monitor backwards channels Give measurment order to MS	
Issue Handover Request		Send measurement results to MSC Request handover	Evaluate handover request Inform new BS
		Evaluate handover requests Request handover	Inform new BS
Task	**MS**	**New BS**	**MSC**
Confirm/ Disconfirm Handover		Accept/block/ delay (queue) handover request	Permit/drop/ delay handover

Table 2 Intelligence distribution among MS, BS and MSC in handover procedures

measurements (see bibliography).

According to the Telecommunications Industry Association (TIA) standards, the BS monitors the backward channels of all MSs with which it is communicating. When it detects a significant drop in the power level, it sends the MS a measurement order. Upon receiving the measurement order, the MS starts taking measurements. The measurement results are reported to the BS with the frequency prescribed in the measurement order. The Pan-European GSM standards suggest that the MS should take measurements all the time and report the results periodically to the BS. This eliminates the need for the BS to constantly monitor all backward channels. A promising method of radio channel measurements would be interactively varying the intervals between the taking and/or reporting of measurements.

Roles of the BS and MSC in Handover Procedures

The BS receives either measurement results only, which it has to evaluate to decide whether a handover is necessary, or the measurement results together with the next BS selected by the MS. In the first case, the BS issues the handover request, if necessary, and sends it to the MSC. Then the MSC picks the best BS to serve the continuation of the call. In the second case, the BS merely sends the MSC the request for handover to the candidate BS specified by the MS. In both cases, the MSC informs the new BS of the handover request.

The new BS, depending on the channel assignment strategy (and possibly the handover prioritization scheme), may accept, block, or queue the handover request. It informs the MSC regarding the status of the handover request. Depending on the response of the new BS, the MSC may permit, delay, or drop the handover request.

Handover Policies

In some channel assignment strategies, the BS handles handover requests in exactly the same manner as it handles originating calls. Obviously, such schemes suggest that the probability of forced termination of an ongoing call due to unsuccessful handover equals the probability of blocking an originating call. From the MS's point of view, however, forced termination of an ongoing call is significantly less desirable than blocking a new call attempt. Therefore, methods for decreasing the probability of forced termination by prioritizing handovers at the expense of a tolerable increase in

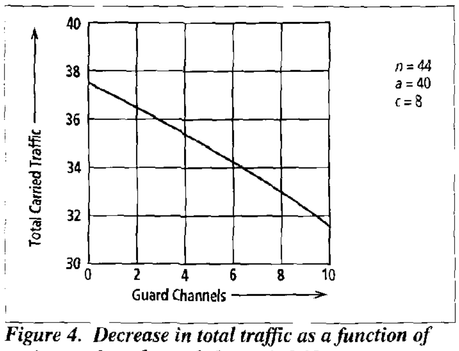

Figure 4. Decrease in total traffic as a function of the number of guard channels [6]

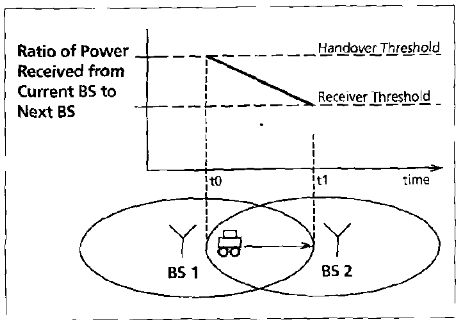

Figure 5. Handover and receiver thresholds. Linear motion from BS 1 to BS 2 is assumed; handover must occur in [t0,t1]

call blocking probability have been devised in order to increase the quality of cellular service. We now present two prioritization schemes.

The Guard Channel Concept

The "guard channel" concept was introduced in the mid-1980s [6, 7]. It offers a generic means of improving the probability of successful handover by simply reserving a number of channels exclusively for handovers. The remaining channels can be shared equally between handovers and originating calls.

The penalty is the reduction of total carried traffic (see Fig. 4) due to the fact that fewer channels are granted to originating calls, and it is the originating calls and not the ongoing calls that really add to the total traffic. This disadvantage can be bypassed by allowing the queuing of originating calls. Intuitively, we can say that the latter method is feasible because originating calls are considerably less sensitive to delay than handover requests.

Another shortcoming of the employment of guard channels, especially with fixed channel assignment strategies, is the risk of inefficient spectrum utilization. Careful estimation of channel occupancy time distributions[1] is essential in order to minimize this risk by determining the optimum number of guard channels.

With flexible or dynamic channel assignment strategies, the guard channel concept is revisited in a modified manner. Cells do not keep guard channels in their possession. The MSC can keep a collection of channels only for handover requests, or it can have a number of flexible channels with associated probabilities of being allocated for handover requests.

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Queuing of Handover Requests

The queuing of handover requests, with or without the employment of guard channels, is another generic prioritization scheme offering reduced probability of forced termination. There is again a tradeoff between the increase in service quality and the corresponding decrease in total carried traffic. Before we discuss its consequences, we briefly describe this scheme.

Handover can occur in the time interval during which the ratio of the power levels received from the current and next BSs is between the "handover threshold" and the "receiver threshold" (see Fig. 5). The handover threshold is set at the point where the power received from the BS of a neighboring cell site has started to exceed the power received from the current BS by a certain amount

[1] *Unencumbered call duration is generally accepted to have an exponential distribution. Due to the memoriless property of the exponential distribution, the duration of the remaining portion of the call after a handover is also exponentially distributed. For a complete analysis of channel occupancy time distributions, the reader is referred to [8].*

One of the aims of our current research is to improve the quality of cellular service by modifying the queue discipline in queuing handovers.

and/or for a certain time. The receiver threshold is the point at which the received power from the BS is at the minimum acceptable level. At this point, since communicating with the current BS is no longer possible, the call will be terminated unless a successful handover to an eligible cell has already occurred. Queuing handover requests is made possible by the existence of the time interval that the MS spends between these two thresholds. The maximum possible waiting time in the queue is given by this interval. The allowable queue size needs to be determined. Computation of the queue size requires knowledge of the traffic pattern of the area, the major factor of which is the expected number of handover requests. In the case of high demand for handovers, the assumption of infinite queue size introduces an undesirably large decrease in total carried traffic [6]. Furthermore, the probability of forced termination is still strictly greater than zero, because the handover request can only wait until the receiver threshold is reached. This is why handover requests are much more sensitive to delay in service than originating calls. Indeed, queuing handovers has been widely discussed; some are in favor of it because of the decrease in the probability of forced termination it offers, while others argue that the delay insensitivity of originating calls makes it more feasible to queue new call attempts rather than handover requests.

One of the aims of our current research is to improve the quality of cellular service by modifying the queue discipline in queuing handovers [9]. The queuing system is not viewed as "first come first serve." A handover request is ranked according to how close the MS stands to (and, possibly, how fast it is approaching) the receiver level. The necessary radio channel measurements are already made; therefore, the only additional complexity in implementing the modification is a fairly simple comparison algorithm to be run continuously on the stored handover requests.

Summary

In this article, we have reviewed various handover scenarios and suggested several ways of distributing intelligence between the MS, BS, and MSC, focusing on their respective roles in these scenarios. We have described the effect of different channel assignment strategies and handover prioritization schemes on BS and MSC functions.

The main criteria used to compare the performance of a cellular system model under different assumptions are probability of call blocking, probability of forced termination, total carried traffic, delay in channel assignment, and number of database lookups. These criteria together define the cost function, the minimization of which, along with quality of service improvement, is the objective. We have proposed a method of prioritizing handover requests by queuing them in such a way that the one with the maximum probability of forced termination is served first.

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Biography

Bijan Jabbari (Senior Member, IEEE) received the B.S. degree from Arya-Mehr University, Tehran, Iran, in 1974, the M.S. and Ph.D. degrees from Stanford University, Stanford, CA, in 1977 and 1981, respectively, all in electrical engineering, and the M.S. degree in engineering-economic systems from Stanford University in 1979. From 1979 to 1981 he was with Hewlett Packard. After graduation, from 1981 to 1983, he was an Assistant Professor at Southern Illinois University, Carbondale, IL. From 1983 to 1985 he was with Satellite Business Systems (now MCI Telecommunications), McLean, VA, where he managed programs on systems requirements definition, system specification, and architecture of the SBS next generation communications system. In 1985, he became Director at M/A-COM Telecommunications for development of Advanced Data Communications Networks. In 1988, he joined the School of Information Technology and Engineering at George Mason University, Fairfax, VA, where he is currently associate professor of Electrical and Computer Engineering. His current research activities include architecture and protocols and performance modeling of broadband telecommunications, intelligent networks, control and signalling for fixed and mobile telecommunications networks. He is a member of Eta Kappa Nu and the Association for Computing Machinery.

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